NASA Conference Publication 3067

FAA/NASA En Route Noise Symposium

Proceedings of a symposium held at
NASA Langley Research Center
Hampton, Virginia
September 12–13, 1989

NASA

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FAA/NASA En Route Noise Symposium

Compiled by
Clemans A. Powell
NASA Langley Research Center
Hampton, Virginia

Proceedings of a symposium sponsored by the National Aeronautics and Space Administration, Washington, D.C., and the Federal Aviation Administration, Washington, D.C., and held in Hampton, Virginia
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I

PREFACE

Aircraft community noise annoyance is traditionally a concern only in localities near airports. The proposed introduction of large commercial airplanes with advanced turboporp propulsion systems with supersonic propellers has given rise to concerns of noise annoyance in areas previously considered not to be impacted by aircraft noise. Preliminary predictions of the noise propagating to the ground while such aircraft are at cruise altitudes and speeds have indicated that their "en route" noise may be clearly audible in areas with low ambient or background noise levels. Thus, en route noise should be considered a potential future noise problem which may require noise certification regulations and limits as has takeoff and approach noise.

A symposium, jointly sponsored by the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) was held at the NASA Langley Research Center September 12-13, 1989 to assess the current knowledge of factors important to the impact of en route noise and to aid in the formulation of FAA and NASA programs in the area. Papers were invited on human response to aircraft noise in areas with low ambient noise levels, aircraft noise heard indoors and outdoors, aircraft noise in recreational areas, detection of propeller and jet aircraft noise, and methodological issues relevant to the design of future studies. This report is a compilation of the presentations made at the symposium which addressed the above issues and consists of measurements of en route noise, data on human response to en route or related noise, experiences related to the major questions of en route noise, and planned research to address those questions.

Clemans A. Powell, NASA Langley Research Center

Richard N. Tedrick, Federal Aviation Administration

Symposium Co-chairmen

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OPENING REMARKS

FAA Perspective and Certification Plans re En Route Noise

James E. Densmore
Director, Office of Environment and Energy
Federal Aviation Administration

Tom Crouch, in his just published book, ***The Bishops Boys***, writes that the years 1900--1905 were the happiest years Wilbur and Orville Wright would know. Orville distilled the sheer joy of these years of invention into one line in one of his letters: "Isn't it astonishing that all of these secrets have been preserved for so many years just so that we could discover them."

The developers of the propfan must have known some of this same excitement in evolving this new technology and its very substantial fuel reduction.

We in the FAA are enthused with the energy saving potential of this new technology, and we needed to ensure that the requirements of the National Environmental Policy Act were met while not impeding the implementation of this important technology. Clearly, the intent of the National Environmental Policy Act is that environmental considerations be a part of development and design. As a consequence, the FAA issued in March 1987 an Advanced Notice of Proposed Rulemaking, which is our formal way of requesting views and information.

After evaluating all the information, including the public comments in the docket, the FAA issued a Notice of Decision in May 1989. Under the Noise Control Act, which added Section 611 to the Federal Aviation Act, the FAA shall not issue an original type certificate for any aircraft for which substantial noise abatement can be achieved by prescribing standards, unless such standards are prescribed and the product meets those standards. Further, the FAA is required to consider economical reasonableness, technological practicability, and appropriateness for the particular type of aircraft. This requirement is also referred to as the Noise Control Act finding. The Notice of Decision stated these requirements and the conclusion that additional information must be developed on en route noise. Therefore, we entered into an accelerated joint research effort with NASA and industry.

There are four general areas of work in that research effort. The first is additional data on atmospheric propagation. In a joint program with the FAA, NASA, and the Air Force, measurements of high-altitude sound propagation were made at Huntsville, Alabama, in the fall of 1987. Additional measurements were made at White Sands, New Mexico, in a joint FAA, NASA program during the spring of 1989. Presentations by Bill Willshire and Ed Rickley will report on these.

The second area is human response research being conducted at NASA Langley. These are controlled studies to better quantify human response to noise from high altitude. Effects of background noise and residential structure attenuation are included, and Dave McCurdy is making a presentation on this work.

In the third area, industry is developing the cost and other impacts of applying noise reduction to aircraft using propfan technology.

The subject of the fourth area of this symposium is the measurement and prediction of community response to noise from high altitude sources. I am very pleased with the excellent response and the range of papers being presented. I believe we will obtain insight important to this new technology. I believe we will also obtain important insight into noise effects remote from airports for existing aircraft.

There has clearly been excellent work in planning this symposium. Dave Stephens and his people have done a fine job, and I would particularly like to acknowledge the individual efforts of Andy Powell and Kevin Sheppard.

STATEMENT BY
REPRESENTATIVE MEL LEVINE

Congress of the United States
House of Representatives
Washington, DC

Thank you for the opportunity to address you here today.

I represent the 27th congressional district in Southern California. Within my district are two heavily traveled airports, Los Angeles International and Santa Monica Municipal Airport. The existence of these airports and the air traffic they generate has become a point of great concern for many of my constituents who have indicated to me that they have recognized significant increases in the volume of air traffic and air noise in the skies over my district. As a result, they have expressed their concern that air traffic policies, and especially those that address the issue of air noise, be revised to accommodate this increased air traffic.

In the GAO report on aircraft noise released in May 1989, the GAO indicates that the FAA west coast plan, currently underway and slated for a 1992 completion, will include a revision of the Los Angeles Basin airspace. This report also states that another result of the plan is that the FAA *"Expects new revised or heavily traveled existing air routes at relatively low altitudes and near populated areas."* Based on these findings, I am concerned that residents may be faced with an even greater increase in both airplane noise and traffic.

I have been working with the FAA to address several noise and safety problems. I have called for an investigation into the dramatic increase in low flying aircraft and the resulting noise they generate. I have also requested a reevaluation of the FAA findings regarding early turn rules, violators of which travel directly over a portion of my district at low altitude. Additionally, I have asked the FAA to evaluate the recent rash of local small plane crashes.

The public perceives the risk of a midair disaster to be great because of the high loss of life that results from accidents such as the Cerritos crash of 1986. I understand that the leading causes of commercial aviation accidents - human factors and weather - receive less attention. However, if the increase in aircraft noise that the residents in my district are hearing is attributable to an increase in aviation traffic, what logically follows is a justifiable concern for the increased possibility of midair collisions, especially under an airspace that has been determined to experience the most near misses in the country. It is my feeling that those with the power to realign our airspace have the responsibility to acknowledge that changes made to our airspace directly affect not only its users but those on the ground as well.

It is time to take a long, hard look at what is occurring in the skies above Southern California. It is not my intent to create in our skies a battlefield between the FAA, general aviation, and residents. However, allowing our skies to become an aerial playground, where the players' conduct goes unchecked, rules are not enforced, and residents below are given little consideration, is no longer acceptable.

Therefore, I urge you today to take action towards developing a plan that would more effectively enforce the current air traffic and air noise regulations, thereby improving the quality of life for those that live near Los Angeles International and Santa Monica Municipal Airports. The assurance that these issues are being actively addressed is long overdue.

Thank you for your time today.

Proposed Definition of the Term "En Route" in "En Route Aircraft Noise."

Maurice A. Garbell
M.A.G. Consultants, Inc.
San Francisco, California.

The Need for a Precise, Formal, Definition.

The current FAA-NASA Symposium affords perhaps the first opportunity for scientists, technicians, and regulators to examine the problem of en route aircraft noise in a formal, dedicated, setting. Whereas the general meaning of the term "en route" might be intuitively understood, it is suggested that a precise formal definition of the term "en route" would be opportune from the outset, especially since the scientific and technical investigation of the problem of noise immissions on the ground from aircraft in flight away from the airspace of an airport may conceivably lead to administrative, regulatory, and legal consequences that would mandatorily require a precise definition of the term "en route."

The Reason for the Proposed Definition.

At this time, certification requirements for aircraft noise under the provisions of ICAO Annex 16 and the U.S. Federal Aviation Regulations Part 36 (FAR 36), Ref. 2, specifically relate to the final approach of aircraft to an airport and the initial climbout from the airport. Both regulations establish precise points at which the concepts set forth in the said regulations begin and end.

More specifically, on approach to an airport, the outermost point of the airport-related airspace is the measurement point **H**, the vertical projection of which, **N**, is a point of the extended runway centerline situated at a distance of 6,562 feet (2,000 meters) from the runway threshold **O** (Ref. 2, Section A36.11(c). For all practical purposes, the flight segment interceding between point **H** and the runway threshold is one of stabilized approach of the aircraft in its final landing configuration, except for a short segment involved in the incipient level-off of the aircraft.

In takeoff, the most distant point considered in the noise certification of aircraft is the noise-measurement station **K** situated at a distance of 21,325 feet (6,500 meters) from the beginning point of the takeoff roll, point **A** (Ref. 1, Section A36.11(b). As a practical matter, the climb with reduced propulsive thrust continues, until the aircraft has attained an altitude of 3,000 feet, at which point maximum climb thrust is restored. That point, designated **F**, can be regarded as the end of the takeoff climb.

Definition of the Term "Airport" in "Airport-Related Aircraft Noise".

The bounds of noise emissions at the source and noise immissions on the ground ascribable to the "*airport operation*" of the aircraft range from point **H** inbound to point **F** outbound.

Definition of the Term "En Route" in "En Route Aircraft Noise."

The term "*en route*" in "*en route aircraft noise*," it is proposed, should encompass the operation of aircraft from point **F** outbound to point **H** inbound per Ref. 1, Section A36, 11(b) and 11(c).

For the purpose of detailed topical analysis of noise immissions from aircraft in en route flight, the following segments of a flightpath may be regarded as portions of the "*en route flight*" of an aircraft, as illustrated in Fig. 1 for the en route descent on final approach and in Fig. 2 for the en route transition from takeoff climb to cruise, plus the cruise flight itself.

I. Cruising Flight.

The definition of "*en route cruise flight*" might be that of prolonged flight at a uniform flight level and changes in flight level from time to time. On long flights, stepwise increases and decreases in flight altitude occur in response to decreasing fuel weight aboard an aircraft and to the exigencies of air traffic control. Such changes in flight level might pose individual en route noise problems.

II. Transition from Cruise to Landing.

Noise immissions on the ground are directly affected by the two principal phases of the en route descent from cruising-flight level to the runway, namely, the initial descent from cruise and the final approach (**Fig. 1**).

II-a. Initial Descent from Cruise.

On termination of a cruise, an aircraft is cleared to descend.

The profile descent begins with the aircraft in its clean configuration and at airspeeds that correspond to the optimal utilization of the kinetic energy of the aircraft and, hence, minimal consumption of energy.

That phase of the descent terminates in a leveling off at a 10,000-foot altitude to reduce the true airspeed to 250 knots.

The next phase comprises a slowdown to initial approach altitude, usually approximately 230 knots, and alignment with a final glidepath.

II-b. Final Approach.

On final approach, beginning at a point approximately 9 to 10 nautical miles (n.mi.) from touchdown. landing flaps are extended in steps, and the landing gear is deployed.

In many noise-sensitive areas, the extension of flaps and landing gear is delayed until the aircraft has crossed the ILS Outer Marker (at a distance of approximately 6 n.mi from touchdown and at an altitude of 1.700 feet).

The functional difference between the initial descent from cruise and the final approach, so far as noise on the ground is concerned, derives from the aerodynamic noise of the airframe with flaps and landing gear extended and the need for the application of engine power to maintain a steady descent against the increased aerodynamic drag of the airframe.

III.Transition from Takeoff Climb to Cruise.

On departure, noise immissions on the ground are directly affected by the two principal phases of the climb from point **F** of thrust restoration at 3,000 feet altitude to cruising level (**Fig. 2**).

III-a. Initial Climb to 10,000 feet altitude.

Having attained a clean configuration, a "*quiet*" zero-flap maneuvering and climbing airspeed, V_{ZF}, and an altitude of 3,000 feet, full climb power is restored and the aircraft accelerates to an airspeed of 250 knots to meet the requirements of air traffic control, until a specified altitude, namely (in the United States and some other countries) 10,000 feet, is attained. At some airports other intermediate airspeed limitations are established, for example, at the Zurich International Airport, where a maximum airspeed of 210 knots is specified for altitudes of up to 3,500 feet).

III-b. Climb from 10,000 feet Altitude or Other Altitude Without an Airspeed Restriction to Optimal Climbing Airspeed to the Intended Initial Cruise Level.

Exiting from the 10,000-foot level (in the U.S.), the aircraft is accelerated to the "optimal-climb" airspeed, that is, that airspeed at which the time or distance rate of total-energy gain is greatest and the Euler-Lagrange derivative of the total-energy gain versus time goes to zero (Ref. 2).

Conclusion.

I submit that the foregoing five flight segments, with their differing airframe configurations, engine thrusts, and airspeed management,

should form the basis for the differential consideration of the noise immissions perceived on the ground underneath or near the afore-defined segments of the flightpath in en route flight, from the end of the initial climb from an airport after takeoff until the final approach to an airport.

References.

1. Code of Federal Regulations, Title 14, 14CFR Part 36, *Noise Standards: Aircraft Type and Airworthiness Certification.* (FAR 36).

2.. Garbell, Maurice A. *Optimum Climbing Techniques for High-Performance Aircraft.* Garbell Aeronautical Series No. 8. Garbell Research Foundation, San Francisco, California. 1953.

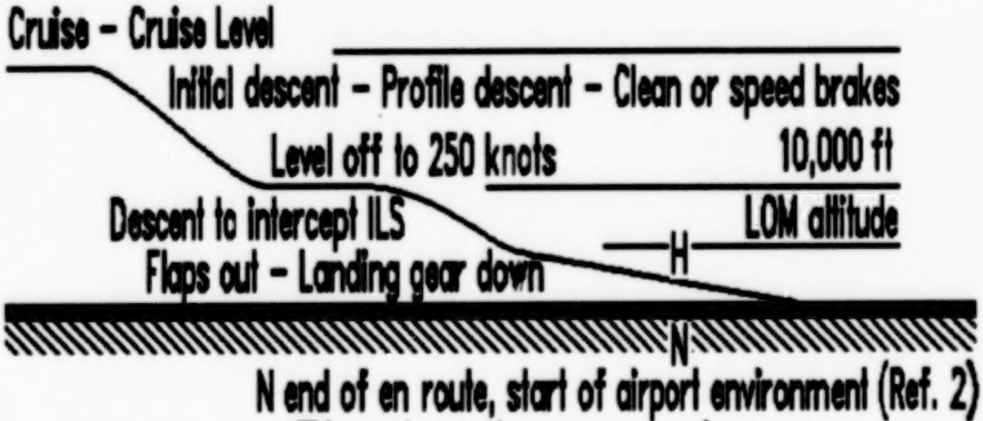


Fig.1. Approach

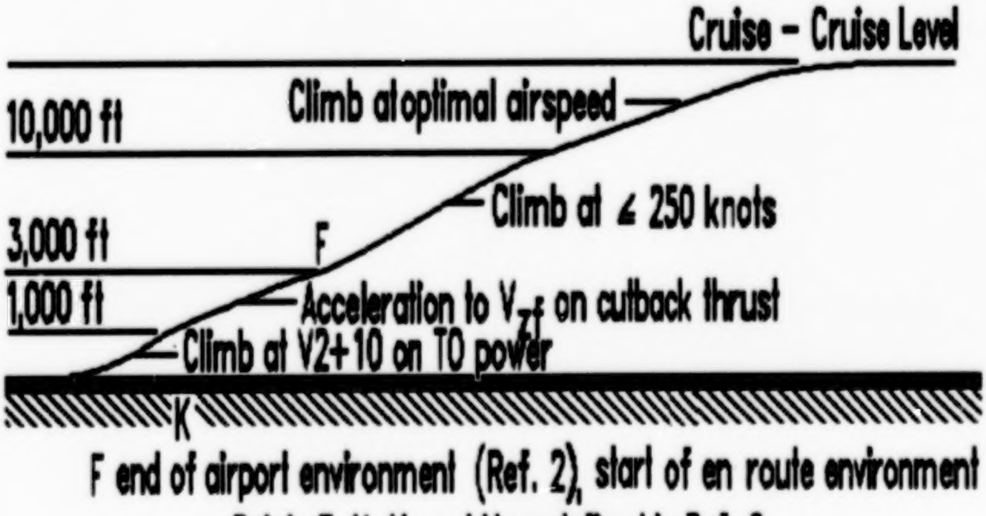


Fig. 2. Takeoff

PTA EN ROUTE NOISE MEASUREMENTS

William L. Willshire, Jr.
NASA Langley Research Center
Hampton, VA

Donald P. Garber
Planning Research Corporation
Hampton, VA

EN ROUTE NOISE TECHNICAL ISSUES

Development of the advanced turboprop has led to concerns about en route noise. Advanced turboprops generate low frequency, periodic noise signatures of relatively high levels. As demonstrated in a flight test of NASA LeRC's Propfan Test Assessment (PTA) airplane in Alabama in October 1987, the noise of an advanced turboprop operating at cruise altitudes can be audible on the ground. The assessment of the en route noise issue is difficult due to the variability in received noise levels caused by atmospheric propagation and the uncertainty in predicting community response to the relatively low-level en route noise, as compared to noise associated with airport operations.

The En Route Noise Test was designed to address the atmospheric propagation of advanced turbroprop noise from cruise altitudes and consisted of measuring the noise of an advanced turboprop at cruise in close proximity to the turboprop and on the ground. The in-flight noise measurements were made by flying an instrumented airplane in formation with the PTA airplane. The ground measurements were made by flying the PTA airplane over a microphone array.

PTA EN ROUTE NOISE MEASUREMENTS

TECHNICAL ISSUES

- PROPAGATION INDUCED VARIABILITY

- SUBJECTIVE RESPONSE

Figure 1

EN ROUTE NOISE TEST GOALS

The En Route Noise experiment had three goals. To acquire a long-range propeller noise database designed to study propagation, to investigate propeller noise variability, and to compare measured propagation data with ray-tracing propagation model predictions.

- **ACQUIRE LONG RANGE (VERTICAL) PROPELLER NOISE DATA BASE DESIGNED TO STUDY PROPAGATION**
- **INVESTIGATE PROPELLER NOISE VARIABILITY**
- **COMPARE MEASURED AVERAGED PROPAGATION DATA WITH RAY TRACING PROPAGATION MODEL**

Figure 2

EN ROUTE NOISE TEST APPROACH

The approach taken to achieve these goals was to perform at White Sands Missile Range a flight experiment using the Propfan Test Assessment airplane. The flight experiment would use multiple-microphone array technology to measure on the ground the noise levels of an advanced turbroprop operating at cruise conditions. The in-flight noise directivity of the advanced turboprop blade passage harmonics would be measured by flying an instrumented aircraft in formation with the test airplane. The in-flight measured directivity of the turboprop would be used as input in propagation models to predict the ground-measured average noise values. Participates in the En Route Noise experiment were NASA Lewis Research Center, the FAA, and NASA Langley Research Center. NASA LeRC was responsible for providing and operating the PTA, and performing the in-flight noise measurements.

- **CONDUCT PTA FLIGHT TEST AT WSMR WITH CONCURRENT WEATHER PROFILES**
- **USE MULTIPLE-MICROPHONE ENSEMBLE-AVERAGING DATA ANALYSIS**
- **MEASURE IN-FLIGHT SOURCE DIRECTIVITY**

Figure 3

PROPFAN TEST ASSESSMENT AIRPLANE

The PTA airplane is shown in this photograph. The PTA airplane is a Gulfstream II with an advance turboprop and engine mounted on its left wing. The advanced turboprop is an eight bladed, 9 ft diameter, single propeller in a tractor configuration. The advanced turboprop operated with supersonic helical tip Mach numbers. The PTA airplane was instrumented with microphones mounted on the inboard boom on the left wing and with surface-mounted microphones on the outside of the fuselage. Engine and turboprop parameters, as well as other pertinent flight parameters, were also measured on board the test airplane.

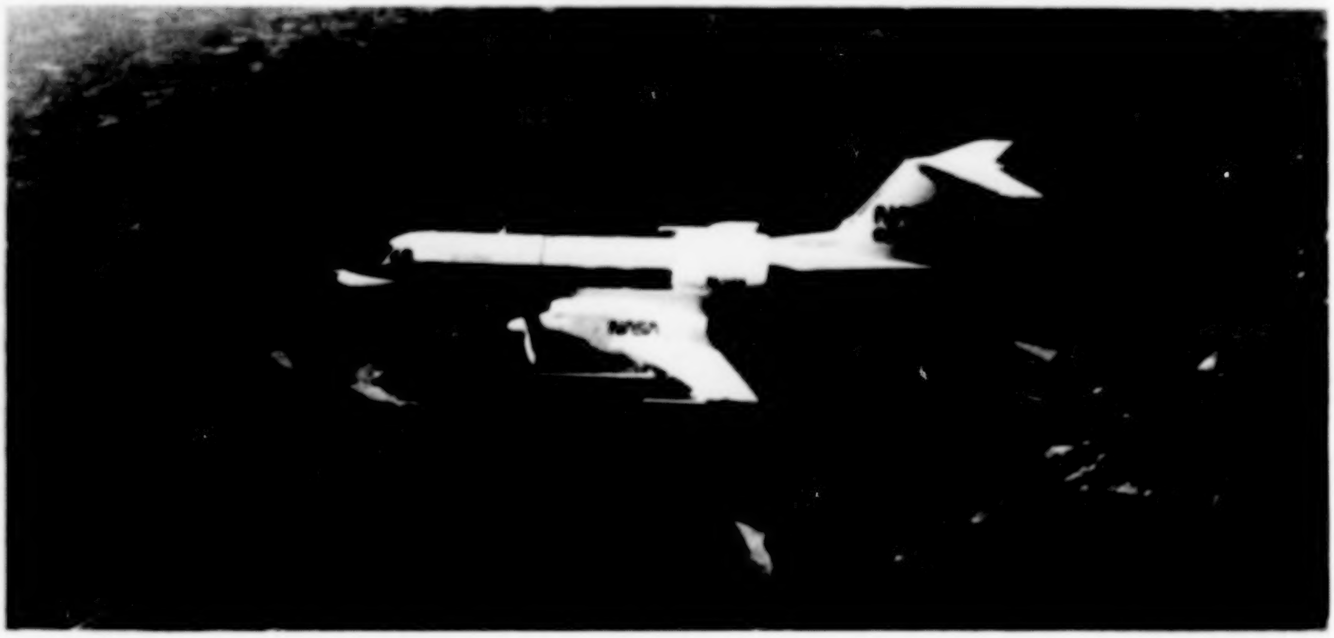
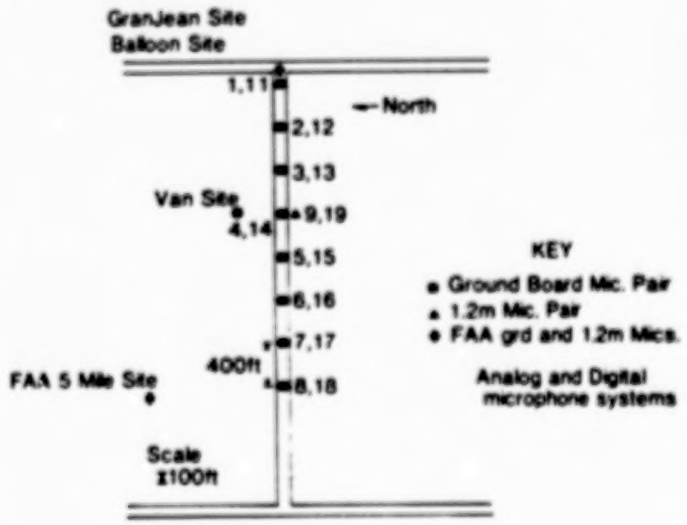


Figure 4

EN ROUTE NOISE TEST MICROPHONE ARRAY

The microphone array used in the En Route Noise test was basically an eight-element linear array with a 400-ft element spacing. The microphone array was located at Gran Jean site in the North Range of WSMR.* Each of the eight array elements was equipped with an analog and a digital microphone system mounted on ground boards. Co-located at one array element were an analog and digital microphone pair mounted 1.2 m above the ground. The FAA had a ground-mounted and a 1.2 m mounted microphone at another element of the microphone array and at a site located approximately5 miles north of the microphone array. The digital microphone systems consisted of standard 1/2-in. condenser microphones with an analog-to-digital converter located in the microphone power supply boxes. In the power supply boxes the analog signal from the microphone was digitized at the rate of 2344 samples per second. The data presented in this paper are from the digital microphone systems. The test airplane flight path was parallel and over the microphone array.



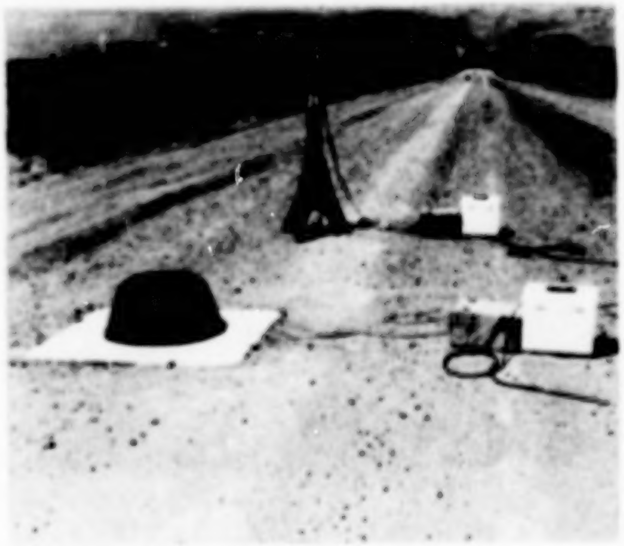


Figure 5

*White Sands Missile Range

EN ROUTE NOISE TEST WEATHER MEASUREMENTS

The various means used to measure weather information are illustrated in this photograph. The primary weather information was obtained from free balloon radiosonde releases. The radiosondes were released from the microphone array site before and after each test session. A typical test session was an hour to an hour and a half. The next important source of weather measurements was a tethered weather balloon system which continuously made profiles up to 1500 m during a test session. Six weather stations of various heights were located in a half-mile circle around the microphone array. An acoustic sounder was located 4 miles northeast of the microphone array.

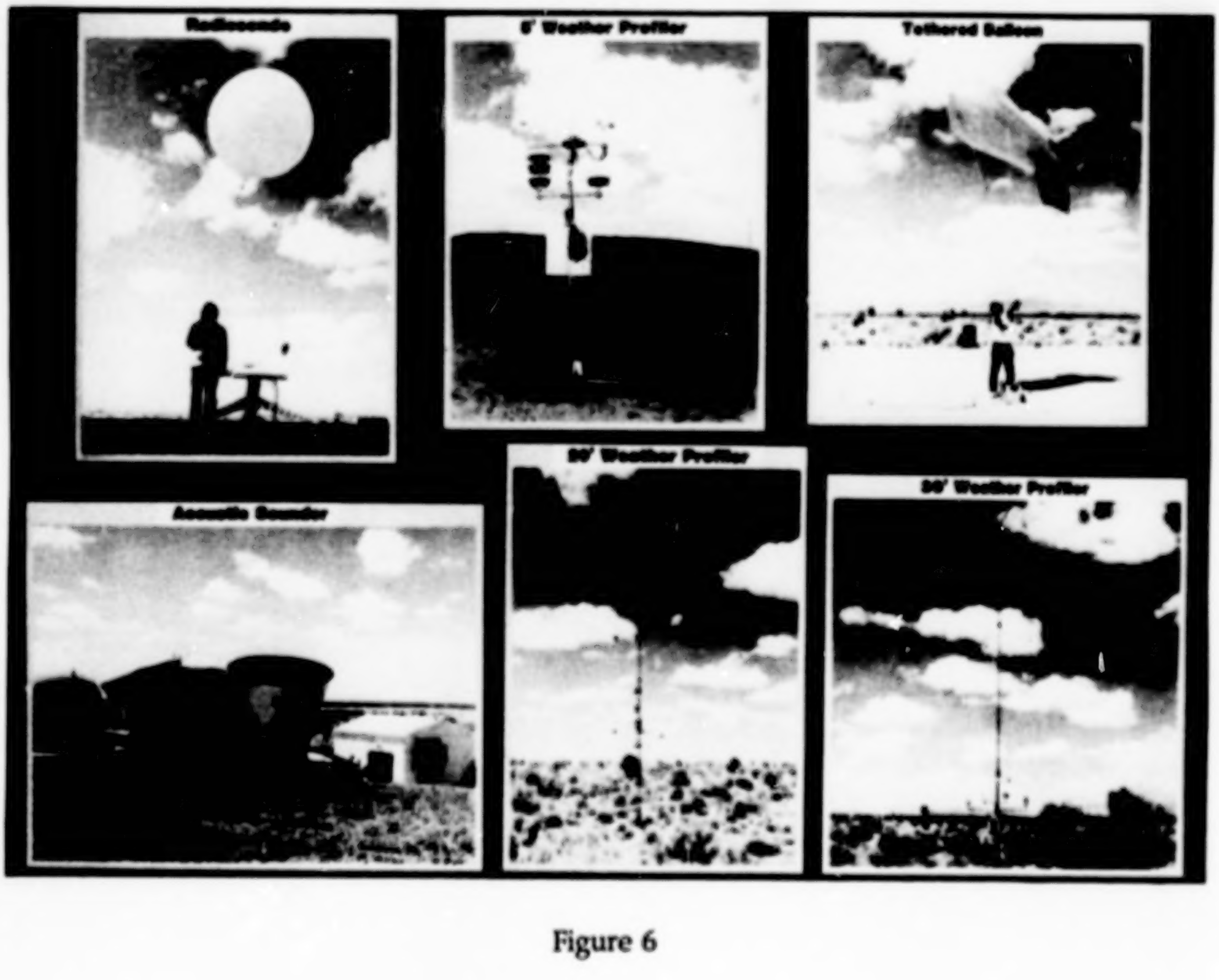


Figure 6

EN ROUTE NOISE TEST COMPLETED TEST MATRIX

The completed test matrix is illustrated in this table. Eighty-eight runs or passes over the microphone array were recorded. The primary test parameters were aircraft Mach number and altitude. The majority of the runs were the high-altitude cruise conditions with a tip speed of 800 ft/s for the advanced turboprop. However, for a limited amount of runs the advanced turboprop tip speed was varied through the range of 620 to 840 ft/s.

PTA SPEED, M	ALTITUDE, 1000 FT. AGL			
	2	9	15	30
.5	4	4	23	
.7			19	32
.77				6

TOTAL RUNS: 88

Figure 7

ENSEMBLE AVERAGING

The data to be presented in this paper were obtained through ensemble averaging of the eight ground-mounted digital microphone systems. The steps in the ensemble process are the individual microphone time histories are high passed filtered at 80 Hz to minimize the influence of wind noise; individual microphone 1/2-second mean square pressure time histories are calculated; each microphone time history is shifted in time based on measured ground speed of the test airplane along the microphone array to give all microphone time histories a common time base; finally the eight shifted time histories are averaged together to form an ensemble average 1/2-second mean square pressure time history. Illustrated in the figure are noise level time histories. However, the ensemble averaging is done on a linear pressure squared basis. The ensemble result, the last plot in the figure, exhibits less variability than the individual microphone time histories.

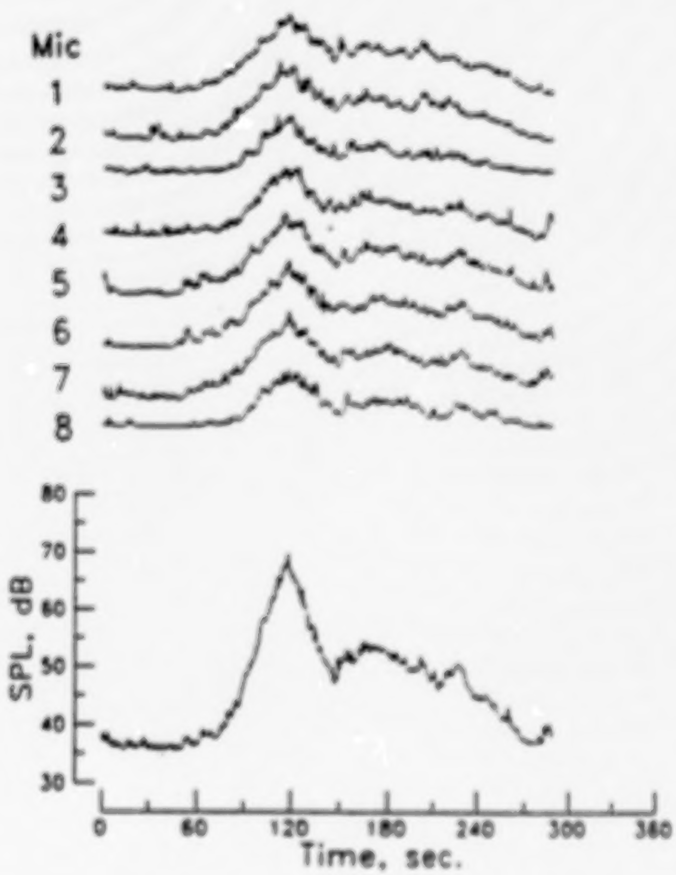


Figure 8

EN ROUTE NOISE TEST ENSEMBLE AVERAGE RESULT

The previous ensemble average result is magnified in this figure for illustration. This example is for a test condition of an airplane speed of Mach .7 and 30,000 ft AGL* altitude. Plotted with the ensemble result are the 80-percent confidence intervals for the average. The 80-percent confidence intervals bound an area in which there is an 80-percent probability that the true average exists. It should be noted that this result and every result to be presented in this paper are from as measured ground level data. The effect of pressure doubling due to the ground-mounted microphones remains in the measured results. Ensemble average time histories like this were calculated for each run. The maximum 1/2-second Overall Sound Pressure Level (SPL) from the ensemble average time histories were determined. In this example the maximum Overall SPL is 70 dB.

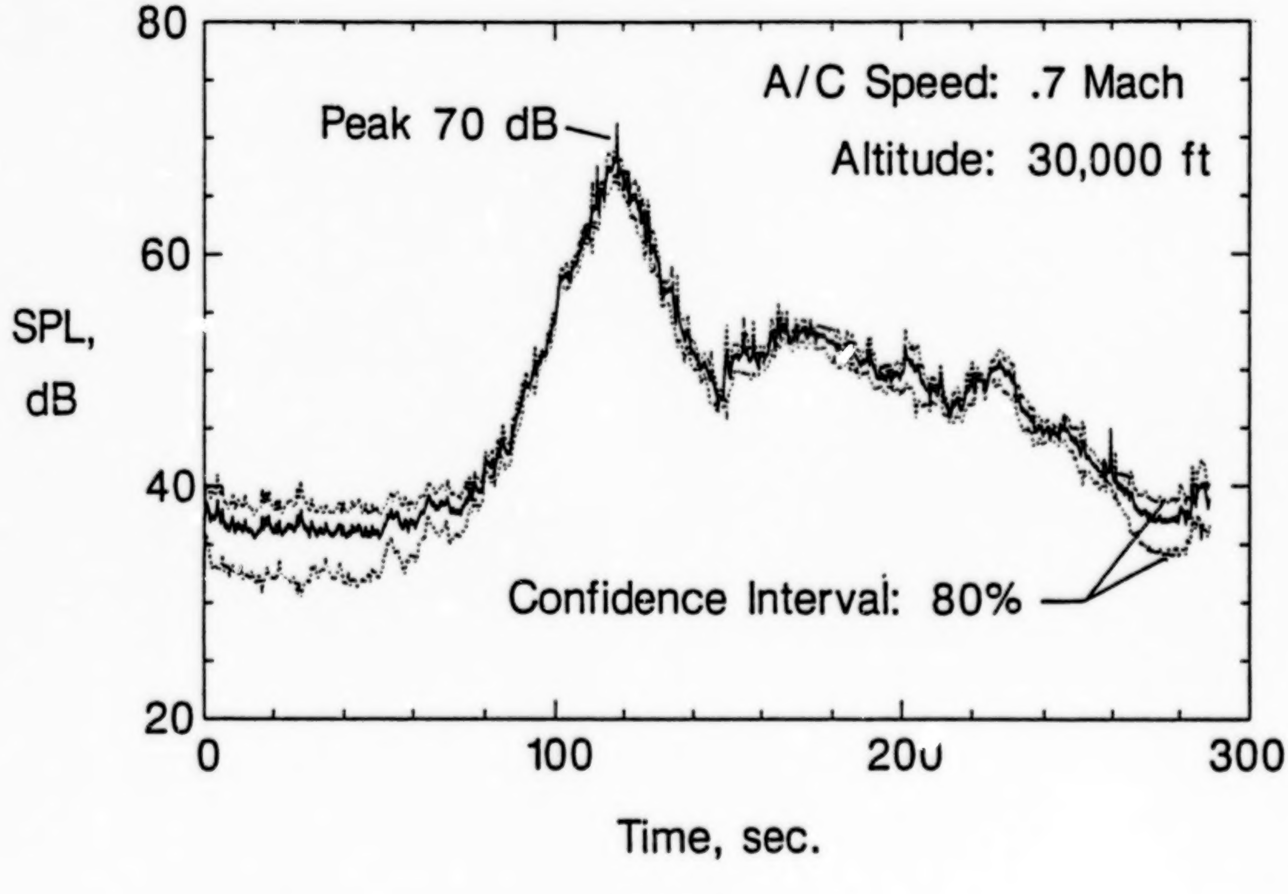


Figure 9

*Above ground level

EN ROUTE NOISE TEST AVERAGE MAXIMUM OVERALL SPL

Average ground level maximum 1/2-second Overall SPL's are given in this table averaged over like-test conditions for the whole database. Average values and the range of the values which went into the averages are given in the table. Approximately 20 runs were averaged for each of the 15 and 30-thousand-foot altitude results. Four runs each were averaged in the 2 and 9-thousand-foot altitude averages. One thing which stands out is the large range associated with the averages. Another is that expected trends might be obscured in the averages by the wide data ranges. For example, in the two 15,000-ft altitude test conditions, there is no change in the average overall SPL for the two test speeds. The lower test speed would be expected to have a lower noise level.

Altitude, 1000 ft AGL

Mach #	2	9	15	30	
.5	91	81	73		Avg
	(86–93)	(80–81)	(70–75)		Range
.7			73	68	Avg
			(66–76)	(60–73)	Range

Figure 10

EN ROUTE NOISE TEST DAILY AVERAGE MAXIMUM OVERALL SPL

In this table are presented daily averages for like-test conditions of maximum ground level maximum 1/2 second Overall SPL. Standard deviations and number of runs in the daily averages are also given in the table. In general there was good repeatability on a daily basis for like-test condition. The standard deviations are often less than 1 dB. On April the 8th, the standard deviation for 11 like-runs was -.8 to .7 dB. However, there was considerable day-to-day variability. For the 30,000 ft, .7-M test condition there was a 12 dB range in average levels. The advanced turboprop source noise, measured in flight, was very consistent within a test day and from test day to test day. The observed average level day-to-day variability is propagation-induced.

		TEST DATE							
TEST CONDITION	KEY	3	4	5	6 A.M.	6 P.M.	8	11	13
30,000 FT., .7 M	AVG, dB	60.8	69.0	60.7	65.1			67.8	72.2
	σ, dB	-1.6/1.2	-.7/.6	-.2/.2	-1./.8			-3.5/1.9	-1./.8
	No.	2	4	4	4			3	4
15,000 FT., .7 M	AVG, dB	75.0	72.6	67.7	69.7	75.0			74.3
	σ, dB	-2.2/1.5	-.5/.5	-1.3/1.0	-1./.8	-2./1.3			-2.1/1.4
	No.	2	2	4	4	3			4
15,000 FT., .5 M	AVG, dB	72.2		70.7	70.2	74.7	74.4		
	σ, dB	-.6/.6		-1.1/.9	-.2/.2	-.1/.1	-.8/.7		
	No.	2		4	3	2	11		

Figure 11

EN ROUTE NOISE TEST AVERAGE SINGLE MICROPHONE DEVIATION

Another way to look at the variability of the ground measured PTA turboprop noise is to look at the distribution of the eight microphones about the ensemble average for the eight microphones. Plotted in this figure is the probability density function of the deviation of the eight single microphones about the ensemble average of four 30,000-ft, .7-M runs measured on the same day. Deviation in this figure is expressed as a percentage and is defined as the difference between a 1/2 second time shifted mean square pressure estimate for a single microphone and the corresponding 1/2-second ensemble average estimate. The difference is then divided by the ensemble average. Deviations were calculated for each microphone time history approximately 20 seconds on either side of the time associated with the maximum overall Sound Pressure Level. The average of the deviations is zero as it should be with a standard deviation of 64 percentage points. Once the actual probability density function is established, probabilities of certain values of deviation can be ascertained. The general shape of the probability density function is skewed to the left with the probability that the deviation from the average is less than 0 being 62 percent. The shape of the PDF and the associated probabilities are typical of the ones measured for other runs and other days.

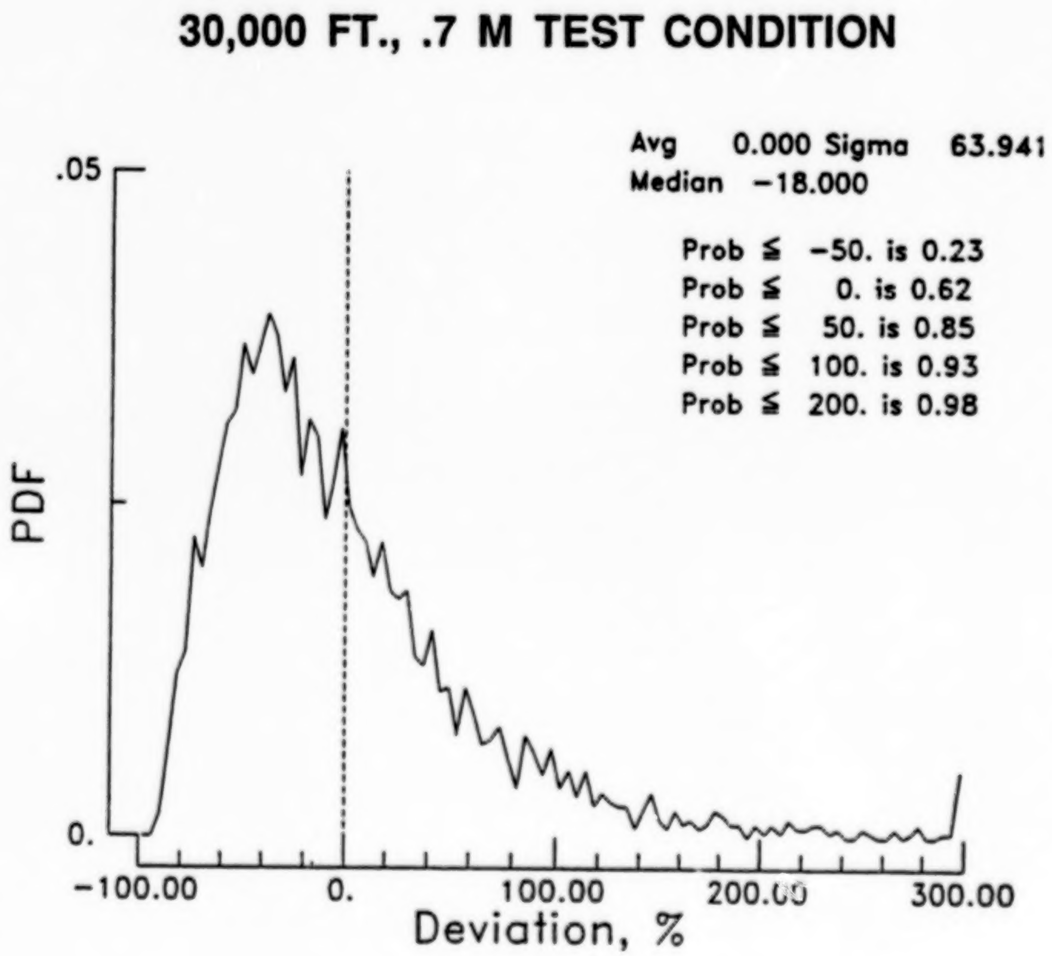


Figure 12

EN ROUTE NOISE TEST NOISE PREDICTION METHOD

In order to produce ray-tracing results to compare with the ground-measured PTA advanced turboprop noise, the following procedure was used. The PTA advanced turboprop source noise levels used as input to the ray-tracing propagation model were predicted using Langley's Aircraft Noise Prediction Program (ANOPP). Measured averaged flight parameters were used to generate a prediction for each test condition. Compared to the measured in-flight noise levels, the ANOPP predicted noise levels were over predicted. In-flight measured noise levels from the chase airplane were used to empirically correct the amplitude of the predicted directivity patterns. The predicted directivity patterns agreed well with the measured ones and were used in the ray tracing because the predicted directivities covered a larger angle range than the measured directivity patterns. The ray-tracing model employed was a 2-dimensional model. Measured flight paths and atmospheric profiles were used in the ray-tracing model. Atmospheric absorption was calculated by the ANSI standard method. A hard ground assumption, 6 dB for pressure doubling for the ground-mounted microphones, was used in the model.

- **Source prediction performed with ANOPP**
  - **measured flight conditions**
  - **source level corrected using "in flight" measured data**
  - **predicted source directivity used**

- **Propagation performed by 2-D ray tracing program**
  - **flight path from C-band radar**
  - **atmospheric profile from free flight balloon launch**
  - **atmospheric absorption by ANSI standard method**
  - **hard ground**

Figure 13

EN ROUTE NOISE TEST COMPARISON OF GROUND MEASURED DATA WITH RAY-TRACE PREDICTION

Run 112

A comparison of a ray-tracing result with ensemble average PTA data is given in this figure for a 30,000-ft, .7-M run. The 80% confidence bounds are included with the ensemble average measured result. The ray-tracing result is the bold solid line. The agreement between measurement and prediction for the flyover is good in amplitude and in shape.

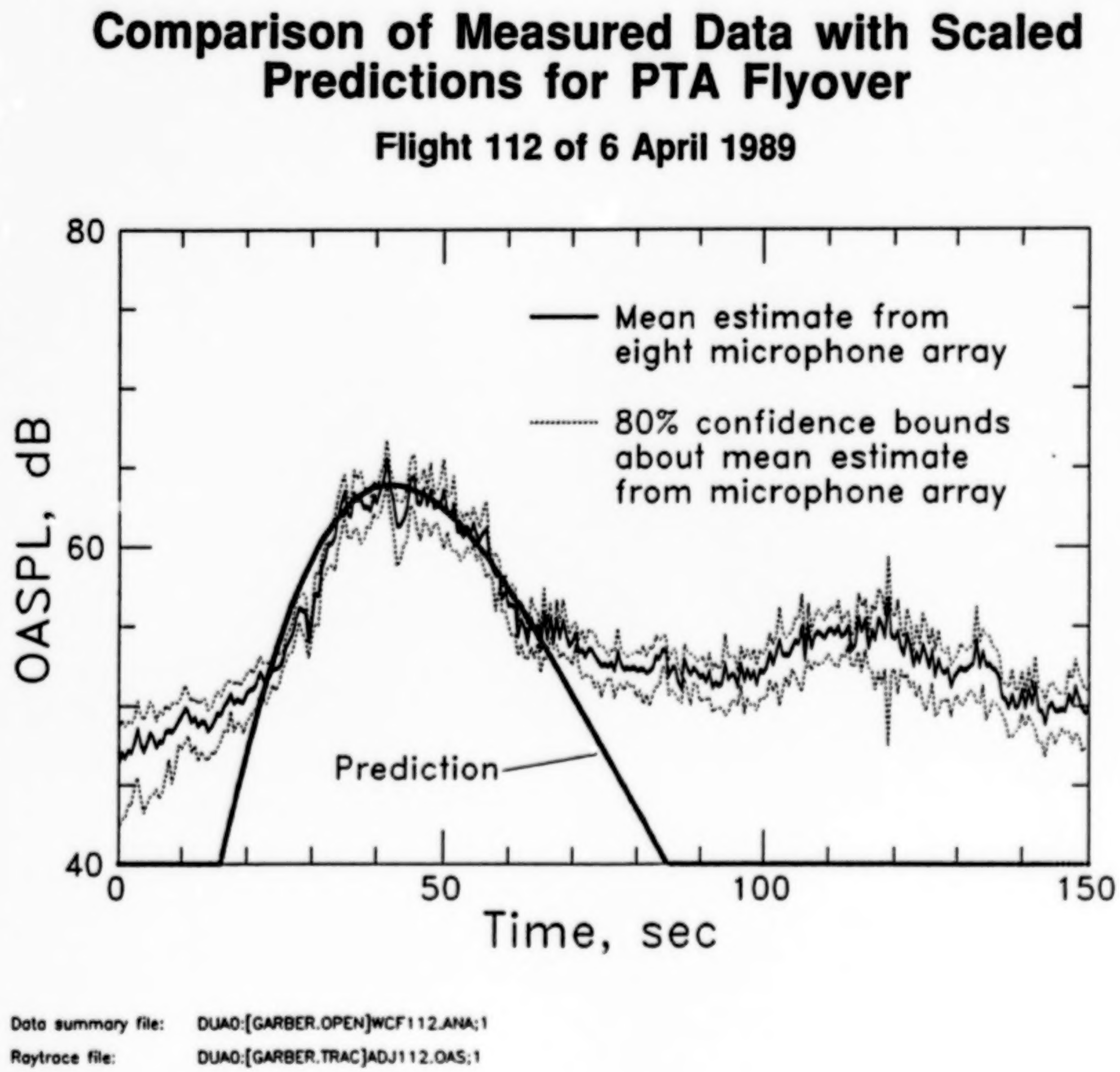


Figure 14

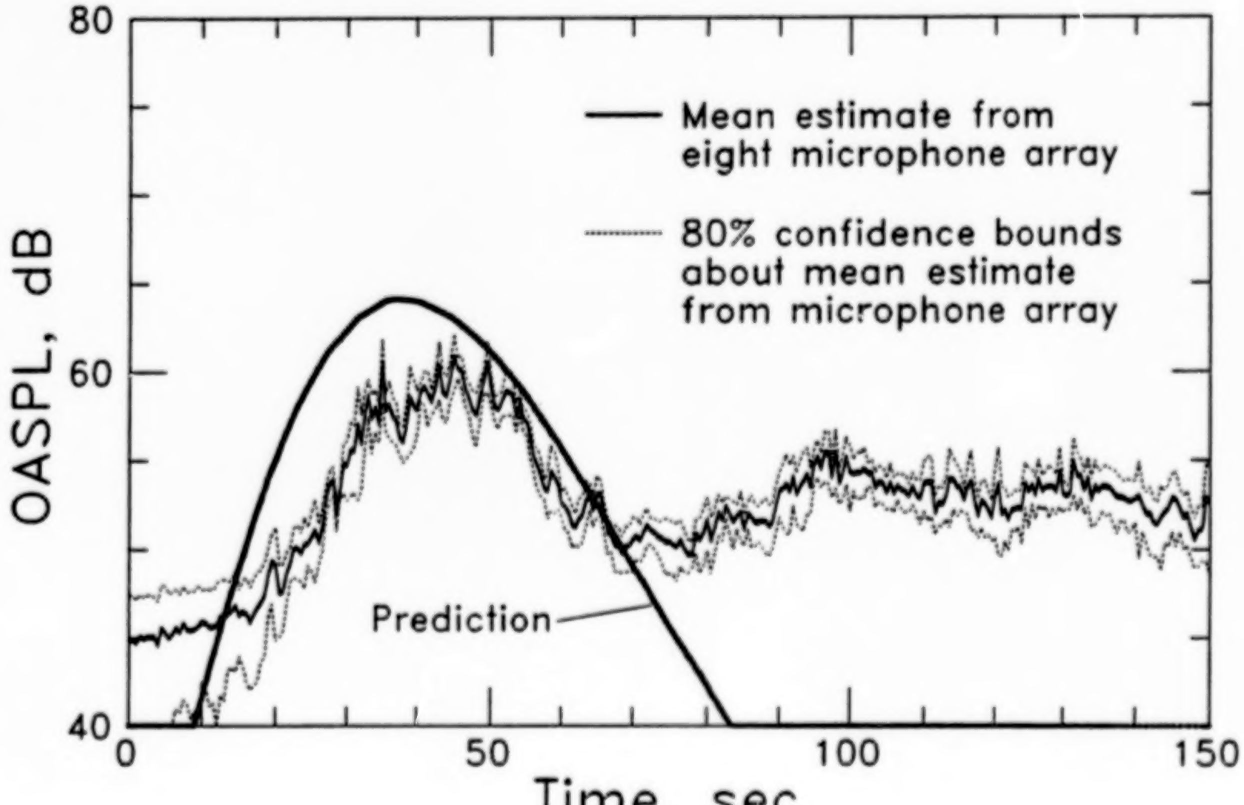
EN ROUTE NOISE TEST COMPARISON OF GROUND MEASURED DATA WITH RAY-TRACE PREDICTION

Run 110

Lest anyone think that there is no problem, in this figure is another comparison between measurement and prediction for another 30,000-ft, .7-M run. The agreement is not as good as in the previous comparison. In this figure the ray-tracing result over-predicted the measured result, and the predicted flyover shape is a little off. Ray tracing does not predict all of the day-to-day variability seen in the measured results. For the 30,000-ft, .7-M test condition, the ray-tracing predictions showed approximately 7 dB variation throughout the test, as compared to the 12 dB variation in the measured average peak 1/2-second Overall SPL

Comparison of Measured Data with Scaled Predictions for PTA Flyover

Flight 110 of 5 April 1989



Data summary file: DUA0:[GARBER.OPEN]WCF110.ANA;1

Raytrace file: DUA0:[GARBER.TRAC]ADJ110.OAS;1

Figure 15

EN ROUTE NOISE TEST CONCLUDING REMARKS

In conclusion, a long-range advanced turboprop en route noise database was obtained with weather, tracking, and onboard measurements. In-flight noise directivity measurements were made. Data repeatability within a test day was excellent. Day-to-day variability existed and is not completely understood and therefore not predicted. Comparison of a two-dimensional ray-tracing propagation model with the ensemble average ground-measured data was good; however, as stated above, the day-to-day data variability was not completely predicted.

Future research will include looking at alternative propagation models. Three-dimensional ray tracing, fast field program, and the parabolic equation are possibilities. The effect of turbulence needs to be accessed.

- **A LONG-RANGE PROPELLER DATA BASE WAS OBTAINED**

- **DATA REPEATABILITY WITHIN A TEST DAY WAS GOOD - VARIABILITY BETWEEN DAYS IS NOT COMPLETELY UNDERSTOOD**

- **COMPARISON OF RAY TRACING PROPAGATION MODEL TO ENSEMBLE-AVERAGED GROUND MEASUREMENTS WAS GOOD - DAY TO DAY VARIABILITY NOT COMPLETELY PREDICTED**

Figure 16

EN ROUTE NOISE - NASA PROPFAN TEST AIRCRAFT
(CORRECTED DATA - SIMPLIFIED PROCEDURE)

E. J. Rickley
Transportation Systems Center
Cambridge MA

September 1989
Letter report
DOT-TSC-FA953-LR4

Prepared for

U.S. Department of Transportation
Federal Aviation Administration
Office of Environment
Washington DC

INTRODUCTION

Surface noise measurements were made by the U.S. Department of Transportation - Transportation Systems Center (DOT/TSC) for the Office of Environment of the FAA during a joint National Aeronautics and Space Administration (NASA) and Federal Aviation Administration (FAA) program to study the high-altitude, low-frequency acoustic noise propagation characteristics of the Advanced Turboprop (propfan) Aircraft. The measurements were made on October 26-31, 1987 in Huntsville, Alabama and on April 3-13, 1989 at the White Sands Missile Range (WSMR), New Mexico.

To effectively compare flight-to-flight data as received on the ground, the procedures and practices of Federal Air Regulation (FAR) Part 36 were used as a guide in adjusting the measured ground data at the time of LA_{max} to a set of reference conditions. After the data for each event were processed using slow detector characteristics, the data record at LA_{max} was then identified and the coordinates of the aircraft at the time of emission were calculated, taking into account atmospheric refraction effects. The effects of atmospheric absorption through the test day and reference day atmosphere were also taken into account and the 1/3-octave data were adjusted accordingly.

1. SLOW SCALE DETECTOR RESPONSE

The corrected raw spectral data (contiguous linear 1/2 second records of data) were processed using a sliding window, or weighted running logarithmic averaging procedure, to achieve an effective "slow" dynamic response characteristic equivalent to the slow response characteristics of sound level meters (2-second exponential averaging) as required under the provisions of FAR 36. The following relationship utilizing four consecutive data records was used:

$$
\begin{aligned}
L_i = 10\times\log \Big[0.17\left(10^{0.1LK-3}\right) \\
+ 0.21\left(10^{0.1Lk-2}\right) \\
+ 0.24\left(10^{0.1Lk-1}\right) \\
+ 0.33\left(10^{0.1Lk}\right)\Big]
\end{aligned}
$$

where i=1/3-octave band number

k=1/2-second data record

2. TEST DAY METEOROLOGICAL DATA

The sound propagation path, source to receiver, was divided into layers as shown in figure 1 (30 meter layers from ground to 2,100 meters; 150 meter layers to 5,100 meters; and 300 meter layers to 12,000 meters). The average temperature, relative humidity, atmospheric pressure, and wind speed and direction were calculated for each

layer from the measured test day meteorological data profiles for use in the "simplified" layered atmospheric adjustment procedure.

3. REFERENCE PARAMETERS

Reference day temperature and pressure versus altitude were obtained from the 1976 US Standard Atmosphere. The reference day relative humidity used is as shown in the following table:

ALTITUDE	RELATIVE HUMIDITY
0 ft.	70%
7,500	40
18,000	23
35,000	20

In addition the following reference conditions were used:

Reference Altitude = 35,000.0 feet
Reference Speed = Test Speed
Wind Speed = 0.0 mph

4. SIMPLIFIED ADJUSTMENT PROCEDURE: LA_{max}

For each flight, the time of reception (tm) of the maximum A-weighted sound pressure level (LA_{max}) was determined. The curved acoustic path, source to receiver, was traced through the test day layered atmosphere, taking into account the refraction due to temperature and wind effects. The geometric coordinates of the aircraft at the time of emission of LA_{max} were determined, as well as the path length through each individual layer, such that the sum of the emission time (te) and propagation time (tp) equaled the reception time (tm=te+tp).

A reference curved acoustic path was likewise traced from the source at a reference altitude of 35,000 feet through the reference layered atmosphere to the reference receiver under the condition that the reference emission angle equaled the test emission angle.

The following adjustments were calculated and added algebraically to the "as measured" LA_{max} and Sound Exposure Level (SEL).

4.1 DELTA 1 CORRECTIONS:

(SPHERICAL SPREADING AND ATMOSPHERIC ABSORPTION)

With a knowledge of both the reference and test day refracted path length, and the path length through each individual layer for the LA_{max} spectra, spherical spreading and atmospheric absorption adjustments were calculated. The absorption adjustments were calculated using the absorption algorithm of the American National Standard (ANSI S1.26-xx) and the layered reference and test day meteorological conditions.

After applying these adjustments to the as measured one-third octave sound pressure levels (SPL) of the LA_{max} spectra, LA_{adj} was calculated.

The Delta 1 correction was derived from the difference between the as measured LA_{max} and the adjusted LA_{adj} levels.

$$\text{Delta } 1 = LA_{max} - LA_{adj}$$

4.2 DELTA 2 CORRECTION (DURATION)

To account for the effects of aircraft speed and distance on the duration of the observed noise data at the receiver, a delta 2 correction was calculated following the procedure of FAR-36.

$$\text{Delta } 2 = 7.5*\log(CPA_t/CPA_r) + 10*\log(Vg_t/Vg_r)$$

CPA_t and CPA_r are the minimum test and reference path lengths (source to receiver), and Vg_t and Vg_r are the test and reference ground speeds respectively. For this report, Vg_t was set equal to Vg_r. The Delta 2 correction is added algebraically to the SEL.

4.3 DELIMP CORRECTION: CHARACTERISTIC IMPEDANCE (Rho-C)

The characteristic impedance correction is derived from the condition of conservation of acoustic power (source to receiver) within a conical ray tube.

The adjustment applied is the difference in the impedance correction calculated for the test day conditions ($IMPCOR_t$) minus the impedance correction calculated for reference conditions ($IMPCOR_r$).

$$DELIMP = IMPCOR_t - IMPCOR_r$$

where:

$$IMPCOR_t = 10*LOG(P_{h1}*T_{h2}*C_{h1})/P_{h2}*T_{h1}*C_{h2})$$

$$IMPCOR_r = 5.6 \text{ dB @ } 35{,}000 \text{ feet}$$

$$IMPCOR_r = 3.0 \text{ dB @ } 20{,}000 \text{ feet}$$

and:

h1 = height of observer (0 ft)

h2 = height to surface of cylinder (Alt-SRR*sinB)

P_{hx} = pressure at height hx

T_{hx} = temperature at hx °K

C_{hx} = speed of sound at hx

4.4 TONE CORRECTION

Although the measured signal was highly tonal in nature and a tone correction of 2-3 dB is indicated using the procedures of FAR-36 referenced to the perceived noise level (PNL) metric, no tone correction adjustments were applied to the A-weighted noise metrics calculated in this report.

4.5 POWER CORRECTION

No power adjustments were applied since complete aircraft operational data was not available at the time of preparation of this report.

5.0 SUMMARY DATA ANALYSIS

Adjustments derived as above (for the test flights at 35,000 feet AGL in Alabama and 30,000 feet AGL in New Mexico) were applied to the A-weighted metrics for both the data from the 1.2 meter and 7 mm microphone measuring systems. The corrected data is shown in tables 1-2 (Alabama - 2 test days, 9 runs) and tables 3-4 (New Mexico - 4 test days, 12 runs). Also included are positional data, calculated corrections, and "as measured" data for each run. The average levels, the standard deviation and the 90% confidence interval of all runs are also provided.

The corrected LA_{max} and SEL data are seen to agree between tests to within 2 and 1 dB respectively. An inspection of the Delta 1 correction gives a good indication of the differing meteorological conditions, both day-to-day and test-to-test. With this in mind, the collapsing of the standard deviation in tables 2-3 (New Mexico) indicates the effectiveness of the atmospheric correction process.

TABLE NO. 1

NASA PROPFAN TEST AIRCRAFT

EN ROUTE NOISE - HUNTSVILLE, ALABAMA

DOT/TSC
8/25/89

CORRECTED DATA*

SITE 1 CENTERLINE 4 FOOT MICROPHONE OCTOBER 26-31, 1987

	CORRECTED		AS MEASURED**		TRACKING					CORRECTION FACTORS			
EV #	AMAX	SEL	AMAX	SEL	SR	SRR	ALT	EMISANG	LATANG	DEL1	DEL2	IMPED	DIST
	dB	dB	dB	dB	ft	ft	ft	deg	deg	dB	dB	dB	dB
10/30/87 FLIGHT 52, 35 kft. AGL, 0.8 Mach, 2963 SHP, Tip Speed: 840 fps													
14-1	59.06	70.18	55.93	67.18	39033.8	38135.9	35759.6	75.0	10.7	2.82	-0.13	+0.31	0.20
15-2	61.24	67.98	57.85	64.66	37861.5	37089.1	35741.2	76.5	-1.7	3.07	-0.07	+0.32	0.18
16-3	55.43	65.31	52.42	62.38	37347.7	36649.3	35640.0	80.4	-5.1	2.69	-0.07	+0.32	0.16
17-4	59.43	68.10	55.76	64.52	38369.6	37605.4	35676.8	75.4	-7.0	3.35	-0.09	+0.32	0.18
18-5	60.21	66.27	56.57	62.70	37536.9	36825.3	35640.0	79.0	-5.0	3.32	-0.07	+0.32	0.17
19-6	60.79	67.46	56.34	63.06	39473.1	38727.9	35667.6	69.7	-1.9	4.14	-0.06	+0.32	0.17
10/31/87 FLIGHT 54, 35 kft. AGL, 0.8 Mach, 2963 SHP, Tip Speed: 840 fps													
14-1	55.52	61.88	52.15	58.17	35232.1	36078.9	34155.4	85.5	-3.1	3.23	-0.04	+0.51	-0.21
16-3	59.42	68.10	54.83	63.17	36253.3	37130.4	34137.3	76.2	-1.0	4.46	-0.04	+0.51	-0.21
17-4	60.42	69.22	55.74	64.20	38083.9	39063.4	34074.1	68.6	-1.7	4.55	-0.04	+0.51	-0.22
AVG	59.05	67.16	55.29	63.34									
STD DEV	2.15	2.50	1.89	2.42									
90% CI	1.33	1.55	1.17	1.50									

* REFERENCE ALTITUDE IS 35000 FEET. ADJUSTMENTS TO REFERENCE CONDITIONS WERE MADE USING THE ABSORPTION ALGORITHM OF THE AMERICAN NATIONAL STANDARD ANS S1.26 WITH A LAYERED U.S. STANDARD ATMOSPHERE, TAKING INTO ACCOUNT SPHERICAL SPREADING, ATMOSPHERIC ABSORPTION AND REFRACTION FOR EACH LAYER.

** NOISE BANDWIDTH 50-1000 Hz ; SLOW-SCALE DETECTOR RESPONSE

TABLE NO. 2 DOT/TSC
NASA PROPFAN TEST AIRCRAFT 8/25/89
EN ROUTE NOISE - HUNTSVILLE, ALABAMA

CORRECTED DATA*

SITE 1 CENTERLINE 7mm MICROPHONE OCTOBER 26-31, 1987

EV #	CORRECTED AMAX	CORRECTED SEL	AS MEASURED** AMAX	AS MEASURED** SEL	TRACKING SR	TRACKING SRR	TRACKING ALT	TRACKING EMISANG	TRACKING LATANG	CORRECTION FACTORS DEL1	CORRECTION FACTORS DEL2	CORRECTION FACTORS IMPED	CORRECTION FACTORS DIST
	dB	dB	dB	dB	ft	ft	ft	deg	deg	dB	dB	dB	dB
10/30/87 FLIGHT 52, 35 kft. AGL, 0.8 Mach, 2963 SHP, Tip Speed: 840 fps													
14-1	59.68	72.21	56.20	68.85	41148.9	40088.2	35759.6	67.9	10.7	3.18	-0.13	+0.31	0.23
15-2	59.66	66.94	57.29	64.64	37018.0	36266.1	35741.2	82.5	-1.7	2.05	-0.07	+0.32	0.18
16-3	54.56	65.39	52.26	63.16	36747.8	36091.6	35640.0	87.5	-5.1	1.98	-0.07	+0.32	0.16
17-4	58.35	66.63	54.40	62.76	38221.7	37464.7	35676.8	76.2	-7.0	3.63	-0.09	+0.32	0.17
18-5	58.44	67.11	54.79	63.53	37537.0	36825.3	35640.0	79.0	-5.0	3.33	-0.07	+0.32	0.17
19-6	59.60	68.39	55.01	63.86	39473.1	38727.9	35667.6	69.7	-1.9	4.28	-0.06	+0.32	0.17
10/31/87 FLIGHT 54, 35 kft. AGL, 0.8 Mach, 2963 SHP, Tip Speed: 840 fps													
14-1	57.49	65.36	53.30	61.10	35232.1	36078.9	34155.4	85.5	-3.1	3.68	0.08	+0.51	-0.21
16-3	59.56	69.27	54.43	64.06	36188.4	37064.9	34137.3	76.6	-1.0	4.62	0.08	+0.51	-0.21
17-4	61.46	70.41	56.30	65.16	38083.9	39063.4	34074.1	68.6	-1.7	4.65	0.09	+0.51	-0.22
AVG	58.75	67.96	54.89	64.12									
STD DEV	1.89	2.30	1.56	2.12									
90% CI	1.17	1.43	0.96	1.31									

* REFERENCE ALTITUDE IS 35000 FEET. ADJUSTMENTS TO REFERENCE CONDITIONS WERE MADE USING THE ABSORPTION ALGORITHM OF THE AMERICAN NATIONAL STANDARD ANS S1.26 WITH A LAYERED U.S. STANDARD ATMOSPHERE, TAKING INTO ACCOUNT SPHERICAL SPREADING, ATMOSPHERIC ABSORPTION AND REFRACTION FOR EACH LAYER.

** NOISE BANDWIDTH 50-1000 Hz ; SLOW-SCALE DETECTOR RESPONSE

TABLE NO. 3
NASA PROPFAN TEST AIRCRAFT
EN ROUTE NOISE - WHITE SANDS, NEW MEXICO

CORRECTED DATA*

SITE 1 CENTERLINE 4 FOOT MICROPHONE APRIL 4-13, 1989

	CORRECTED		AS- MEASURED**		TRACKING					CORRECTION FACTORS			
EV #	AMAX	SEL	AMAX	SEL	SR	SRR	ALT	EMISANG	LATANG	DEL1	DEL2	INPED	DIST
	dB	dB	dB	dB	ft	ft	ft	deg	deg	dB	dB	dB	dB
04/04/89 30 kft. AGL, 0.7 Mach, 90% SHP, Tip Speed: 800 fps													
103	57.75	66.80	58.28	66.94	33630.5	37955.6	30949.7	72.7	-0.1	-1.58	0.40	+1.05	-1.05
104	57.48	67.22	58.15	67.50	34659.1	38808.4	30998.9	69.4	0.0	-1.54	0.39	+0.87	-0.98
105	59.79	67.55	60.55	67.91	35436.3	40076.0	31034.3	65.6	-0.1	-1.81	0.40	+1.05	-1.07
106	55.59	66.51	56.25	66.77	33384.2	37473.0	30975.9	74.6	0.0	-1.53	0.39	+0.87	-1.00
04/05/89 30 kft. AGL, 0.7 Mach, 90% SHP, Tip Speed: 800 fps													
107	51.97	61.76	48.94	58.36	35141.3	39798.4	30878.9	67.7	-0.1	2.13	0.37	+0.90	-1.08
108	53.39	63.11	50.30	59.62	34446.7	38751.0	30938.6	69.5	-0.1	2.18	0.40	+0.90	-1.02
109	53.56	62.72	50.78	59.54	33761.1	38121.7	30928.7	71.8	-0.1	1.87	0.40	+0.91	-1.06
110	51.35	62.34	49.41	60.00	32528.3	36654.6	30920.1	79.1	-0.1	1.03	0.40	+0.91	-1.04
04/06/89 30 kft. AGL, 0.7 Mach, 90% SHP, Tip Speed: 800 fps													
111	59.50	68.50	56.44	65.07	34461.1	38597.9	31215.3	70.3	-0.1	2.31	0.37	+0.75	-0.99
112	59.87	67.51	56.60	63.87	34747.0	38784.2	31154.6	69.4	0.0	2.51	0.38	+0.76	-0.96
113	57.40	67.30	54.31	63.81	34481.8	38550.8	31196.7	70.2	0.0	2.33	0.37	+0.77	-0.97
114	56.90	66.93	53.66	63.32	34667.6	38654.1	31205.5	69.9	-0.1	2.47	0.37	+0.77	-0.95
04/13/89 30 kft. AGL, 0.7 Mach, 90% SHP, Tip Speed: 800 fps													
117	58.72	68.02	63.01	71.84	33327.2	38440.0	30283.6	70.6	0.0	-5.12	0.47	+0.83	-1.24
119	61.05	69.13	65.50	73.12	33928.1	39098.1	30306.8	68.5	0.0	-5.29	0.47	+0.83	-1.23
120	59.89	69.37	64.09	73.10	33213.4	38204.7	30297.3	71.6	0.0	-5.03	0.47	+0.83	-1.22
122	57.34	66.36	61.39	69.94	33851.0	38909.6	30289.0	69.0	0.0	-4.88	0.47	+0.84	-1.21
AVG	56.97	66.32	56.73	65.67									
STD DEV	3.00	2.45	5.27	4.83									
90% CI	1.31	1.07	2.31	2.11									

* REFERENCE ALTITUDE IS 35000 FEET. ADJUSTMENTS TO REFERENCE CONDITIONS WERE MADE USING THE ABSORPTION ALGORITHM OF THE AMERICAN NATIONAL STANDARD ANS S1.26 WITH A LAYERED U.S. STANDARD ATMOSPHERE, TAKING INTO ACCOUNT SPHERICAL SPREADING, ATMOSPHERIC ABSORPTION AND REFRACTION FOR EACH LAYER.

** NOISE BANDWIDTH 50-1000 Hz ; SLOW-SCALE DETECTOR RESPONSE

TABLE NO. 4

NASA PROPFAN TEST AIRCRAFT

EN ROUTE NOISE - WHITE SANDS, NEW MEXICO

DOT/TSC
8/25/89

CORRECTED DATA*

SITE 1 CENTERLINE 7mm MICROPHONE APRIL 4-13, 1989

	CORRECTED		AS- MEASURED**		TRACKING					CORRECTION FACTORS			
EV #	AMAX	SEL	AMAX	SEL	SR	SRR	ALT	EMISANG	LATANG	DEL1	DEL2	IMPED	DIST
----	-----	-----	-----	-----	-------	-------	-------	-----	-----	----	-----	-----	----
	dB	dB	dB	dB	ft	ft	ft	deg	deg	dB	dB	dB	dB
04/04/89 30 kft. AGL, 0.7 Mach, 90% SHP, Tip Speed: 800 fps													
103	58.08	68.56	58.67	68.75	33630.6	37955.3	30953.7	72.7	-0.1	-1.64	0.40	+1.05	-1.05
104	56.96	69.49	57.39	69.52	31975.1	35975.3	31025.2	87.1	-0.1	-1.30	0.39	+0.87	-1.02
105	61.58	68.96	62.31	69.29	35436.4	40076.0	31034.3	65.6	-0.1	-1.78	0.40	+1.05	-1.07
106	57.34	69.07	58.06	69.39	33488.3	37583.2	30978.9	74.1	0.0	-1.59	0.39	+0.87	-1.00
04/05/89 30 kft. AGL, 0.7 Mach, 90% SHP, Tip Speed: 800 fps													
107	51.51	62.58	49.53	60.22	32464.2	36661.1	30908.4	82.6	-0.1	1.09	0.37	+0.90	-1.06
108	52.79	65.37	49.57	61.74	34446.7	38751.0	30938.6	69.5	-0.1	2.32	0.40	+0.90	-1.02
109	52.61	63.91	49.81	60.70	33761.1	38121.7	30928.7	71.8	-0.1	1.90	0.40	+0.91	-1.06
110	51.60	64.34	49.83	62.17	31842.0	35906.4	30933.2	88.3	-0.1	0.86	0.40	+0.91	-1.04
04/06/89 30 kft. AGL, 0.7 Mach, 90% SHP, Tip Speed: 800 fps													
111	58.07	69.35	54.96	65.87	34460.9	38597.9	31215.3	70.3	-0.1	2.36	0.37	+0.75	-0.99
112	57.87	68.76	54.56	65.07	34747.0	38784.2	31154.6	69.4	0.0	2.55	0.38	+0.76	-0.95
113	55.80	68.18	52.64	64.64	34481.8	38550.8	31196.7	70.2	0.0	2.40	0.37	+0.77	-0.97
114	55.93	67.16	53.85	64.71	32796.9	36626.5	31221.0	79.4	-0.1	1.31	0.37	+0.77	-0.96
04/11/89 30 kft. AGL, 0.7 Mach, 90% SHP, Tip Speed: 800 fps													
115	54.95	66.19	59.58	70.39	33510.4	38356.7	30581.4	71.0	-0.1	-5.64	0.44	+1.00	-1.17
116	56.30	65.86	60.29	69.42	33007.2	37524.6	30557.0	74.3	0.0	-5.00	0.44	+1.00	-1.11
118	52.77	66.10	56.29	69.18	33932.6	38577.3	30540.4	70.1	0.0	-4.53	0.45	+1.00	-1.11
04/13/89 30 kft. AGL, 0.7 Mach, 90% SHP, Tip Speed: 800 fps													
117	57.47	68.17	61.93	72.16	33744.7	38936.0	30295.8	68.9	0.0	-5.29	0.47	+0.83	-1.24
119	59.70	69.56	64.38	73.78	33765.4	38905.2	30306.5	69.1	0.0	-5.51	0.47	+0.83	-1.23
120	58.84	69.72	63.09	73.50	33852.0	38934.5	30292.2	69.0	0.0	-5.08	0.48	+0.83	-1.22
122	57.25	67.20	61.52	70.99	34359.4	39491.2	30291.4	67.2	0.0	-5.01	0.47	+0.84	-1.21
AVG	56.18	67.29	56.75	67.44									
STD DEV	2.82	2.13	4.93	4.22									
90% CI	1.10	0.83	1.93	1.65									

* REFERENCE ALTITUDE IS 35000 FEET. ADJUSTMENTS TO REFERENCE CONDITIONS WERE MADE USING THE ABSORPTION ALGORITHM OF THE AMERICAN NATIONAL STANDARD ANS S1.26 WITH A LAYERED U.S. STANDARD ATMOSPHERE, TAKING INTO ACCOUNT SPHERICAL SPREADING, ATMOSPHERIC ABSORPTION AND REFRACTION FOR EACH LAYER.

** NOISE BANDWIDTH 50-1000 Hz ; SLOW-SCALE DETECTOR RESPONSE

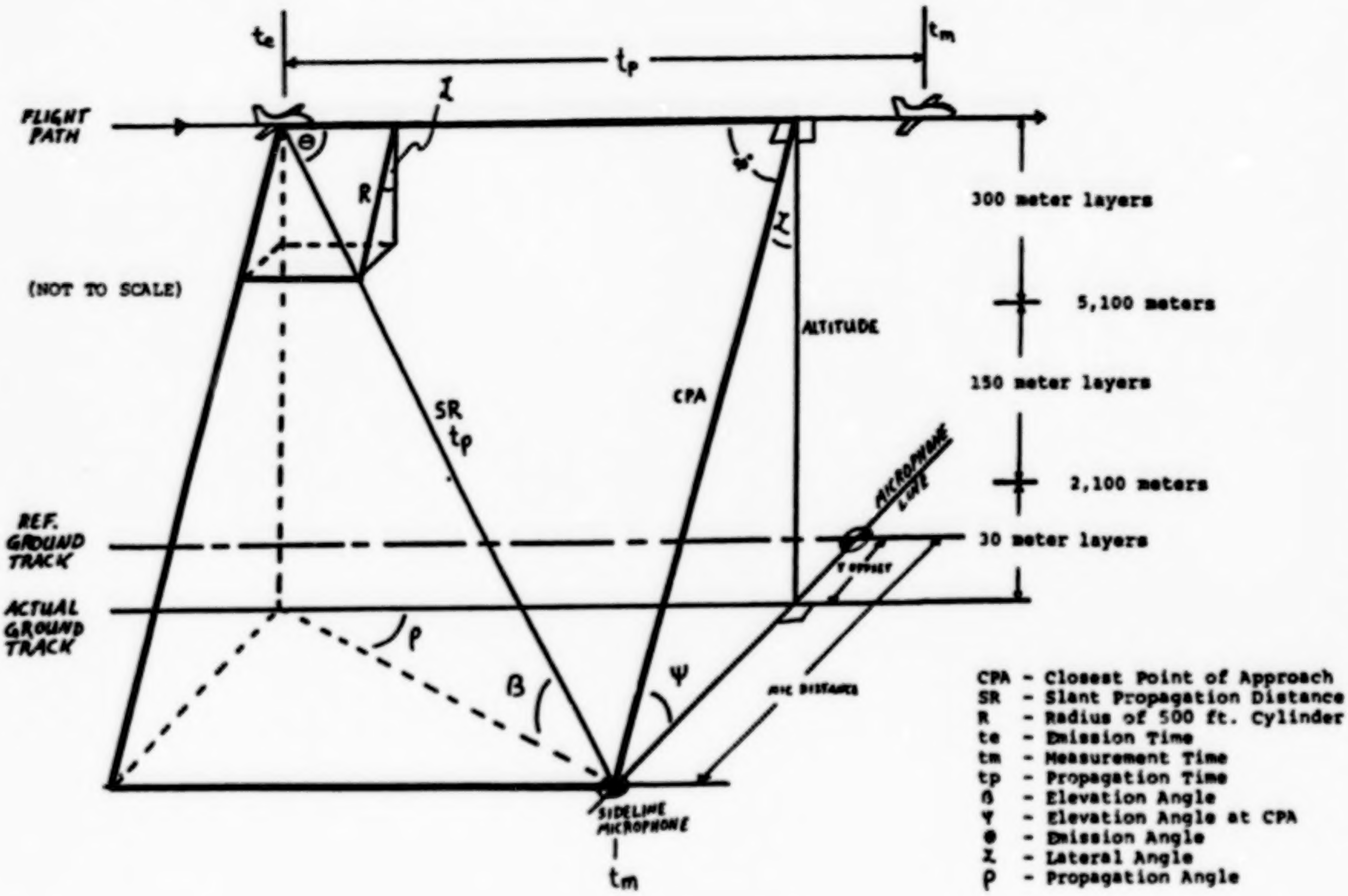


FIG. 1 FLIGHT GEOMETRY

EN ROUTE NOISE - NASA PROPFAN TEST AIRCRAFT

(CALCULATED SOURCE NOISE)

E.J. Rickley
Transportation Systems Center
Cambridge MA

September 1989
Letter report

DOT-TSC-FA953-LR5

Prepared for

U.S. Department of Transportation
Federal Aviation Administration
Office of Environment
Washington DC

1. INTRODUCTION

The second phase of a joint National Aeronautics and Space Administration (NASA) and Federal Aviation Administration (FAA) program to study the high-altitude, low-frequency acoustic noise propagation characteristics of the Advanced Turboprop (propfan) Aircraft was conducted on April 3-13, 1989 at the White Sands Missile Range (WSMR), New Mexico. The first phase was conducted on October 26-31, 1987 in Huntsville, Alabama. These en route noise investigations were conducted as part of the NASA Propfan Test Assessment (PTA) high altitude flight test program.

Surface noise measurements were made by the U.S. Department of Transportation - Transportation Systems Center (DOT/TSC) for the Office of Environment of the FAA. NASA (Lewis) measured the source noise of the test aircraft during both phases while NASA (Langley) measured surface noise only during the second phase.

A unique feature of the propfan engine is the noise it generates. The unshrouded blades of a propfan engine propagate more low frequency acoustic energy, especially at the blade passage frequency (BPF) and its harmonics, than conventional shrouded jet aircraft. Low-frequency noise is absorbed to a lesser extent by the atmosphere than the high-frequency noise from conventional jet aircraft.

FAA/NASA designed a program to obtain noise level data from the propfan test bed aircraft, both in the near field and at ground level, during simulated en route flights (35,000 and 20,000 feet ASL), and to test low frequency atmospheric absorption algorithms and prediction technology to provide insight into the necessity for regulatory measures.

2. EXPERIMENTAL APPROACH

The acoustic noise propagation characteristics of the NASA SR-7L propfan, driven by a 6000 SHP Allison Model 501-M78 engine mounted on a modified Gulfstream GII test bed aircraft, were measured during the periods of October 26-31, 1987 (Alabama) and April 3-13, 1989 (New Mexico). NASA (LeRC) measured the source noise of the PTA test bed aircraft using an instrumented Learjet chase plane at prescribed locations on the surface of a 500 foot cylinder around the propfan engine. In addition, NASA measured the source noise on the test bed aircraft itself, using wing-boom and fuselage mounted sensors.

Surface noise measurements were made by TSC when the PTA aircraft (without chase plane) was flown at nominal altitudes of 35,000 and 20,000 feet (AGL) in Alabama, and by both NASA (Langley) and TSC when the PTA aircraft was flown at nominal altitudes of 30,000, 15,000 and 2,000 feet (AGL) in New Mexico.

Five surface measurement sites were deployed by TSC in Alabama: one each under the flight path and at ±5 miles and ±10 miles laterally from the flight track. Two sites were deployed by TSC in New Mexico: one under the flight track and one positioned 5 miles laterally from

the flight track. In addition to 4.0-foot microphones, inverted ground plane microphones were used at each site. Each inverted microphone was mounted with a 7 mm gap on a metal ground plate, 40-cm in diameter.

NASA provided aircraft position data synchronized to the recorded noise data. Weather balloons were launched 10 miles south of the surface noise measuring sites in Alabama and at the measuring site in New Mexico to obtain a meteorological data profile during the tests.

3. MEASUREMENT DATA

Figures 1-2 contain synchronized graphic level time histories as measured at the five measurement sites in Alabama. The representative data presented for flights at 35,000 and 20,000 feet (AGL), show the temporal nature of the aircraft sound at the ground measurement stations and the relative time of arrival of the sound at the centerline and ±5 and ±10 mile sites.

Figures 3-4 contain synchronized history data from the New Mexico tests for representative flights at 30,000 and 15,000 feet AGL at the centerline and 5 mile sites. Figure 5 contains noise level history data for a representative fly-by at 2,000 feet (AGL) only at the centerline measuring station.

For comparison, figures 6-7 contain graphic level time history data for several en route commercial jet aircraft using the same time scale and detector averaging characteristics (fast sound level meter response).

4. SOURCE NOISE

Using an instrumented Learjet aircraft as a chase plane, NASA measured the source noise of the PTA test bed aircraft at prescribed points relative to the power plant on the surface of an imaginary 500 foot cylinder around the propfan.

Plots of the NASA Alabama source data at nominal altitudes of 35,000 and 20,000 feet AGL are shown in figures 8 and 9.

5. CALCULATED SOURCE NOISE

To test the low-frequency absorption algorithm, adjustments were applied to the TSC "as measured" 7mm ground data to adjust the levels back to the source. (Or, more specifically, to the surface of the imaginary 500 foot cylinder around the propfan source.) A direct comparison with the NASA chase plane data could then be made.

The following adjustments were applied:

1) Free field adjustment
2) Spherical spreading losses

3) Atmospheric absorption
4) Characteristic impedance (Rho-c)

After adjustment as above, like events were grouped (e.g. by altitude, speed, measurement site) and the BPF* tone level (1/3-octave band data) versus emission angle were entered into a curve fitting program to obtain a second-order best fit curve.

Approximately ten points were selected for curve fitting over the period of each event. These included the maximum level and intermediate points where the measured signal was found to "peak" (i.e.: points representing the peak envelope (see figure 10). The resultant calculated noise source data are presented in paragraphs 5.1 and 5.2

5.1 ALABAMA TEST

Figures 11-12 contain calculated source noise data derived from ground measurements at the Alabama centerline and ±5 and ±10 mile measurement sites (nominal altitudes of 35,000 and 20,000 feet AGL; shaft horsepower: 4658; propeller tip speed: 840 fps).

Figure 13, derived from ground level measurements at the centerline site, contains calculated source noise data from overflights at 20,000 feet with two shaft horsepower settings (4658 and 3853 SHP) and three propeller tip speed settings (840, 700 and 620 fps).

5.2 NEW MEXICO TEST

Figures 14-15 contain calculated source noise data derived from the New Mexico ground measurements at the centerline and 5 mile sites (nominal altitudes of 30,000 and 15,000 feet AGL; 90% SHP; 800 fps).

Figure 16 presents a comparison of the calculated source data derived from New Mexico centerline data with the aircraft at nominal altitudes of 15,000 and 2,000 feet AGL (90% SHP; 800 fps). Figure 17 contains calculated source data with the aircraft at 30,000 feet AGL for four different operating parameters.

6. SUMMARY

The curves of calculated source noise versus emission angle are based on a second order best-fit curve of the peak envelope of the adjusted ground data. Centerline and sideline derived source noise levels are shown to be in good agreement. A comparison (figures 18-19) of the Alabama "chase plane" source data and the calculated source noise at centerline for both the Alabama and New Mexico data shows good agreement for the 35,000 and the 20,000 feet (ASL) overflights. With the availability of the New Mexico in-flight data, further in depth comparisons will be made.

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*blade passage frequencies

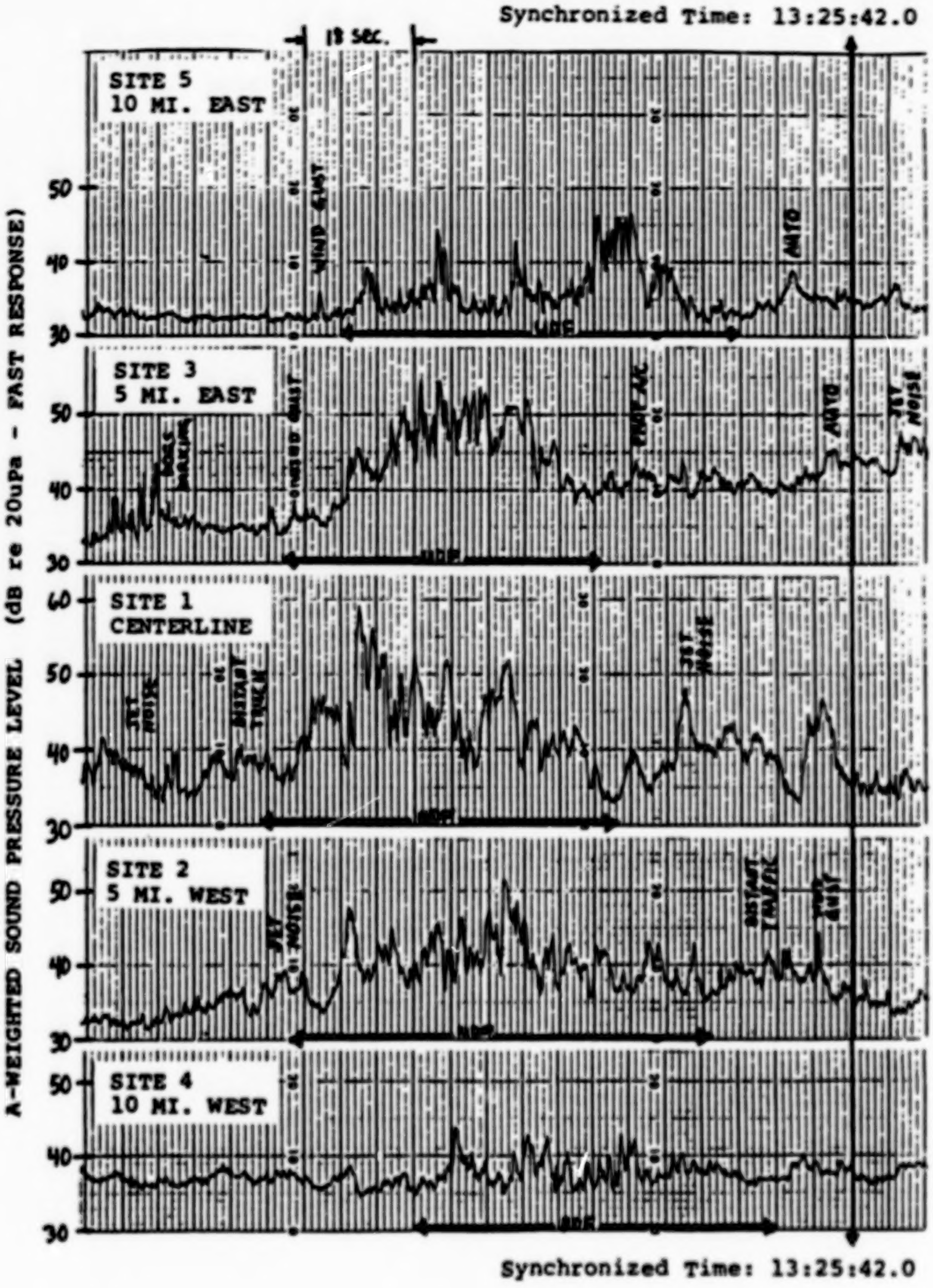


FIG. 1 SYNCHRONIZED NOISE LEVEL TIME-HISTORIES
EN ROUTE NOISE - HUNTSVILLE, AL

Flight 52 Event 19-6 10/30/87
35kft., 0.8 MACH, 2963 HP, 840 fps

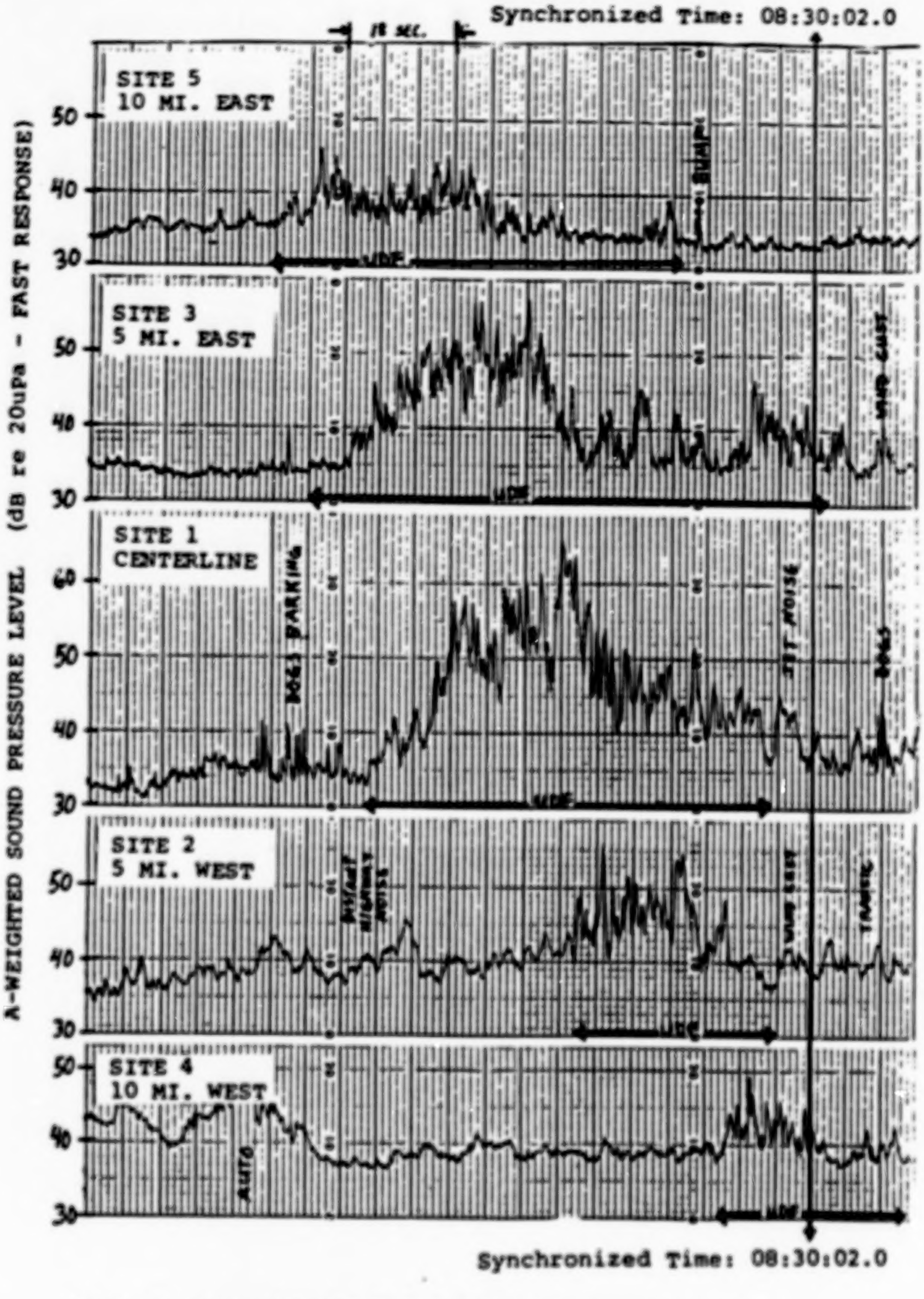


FIG. 2 SYNCHRONIZED NOISE LEVEL TIME-HISTORIES
EN ROUTE NOISE - HUNTSVILLE, AL

Flight 51 Event 15-2 10/30/87

20kft., 0.7 MACH. 4658 HP. 840 fps

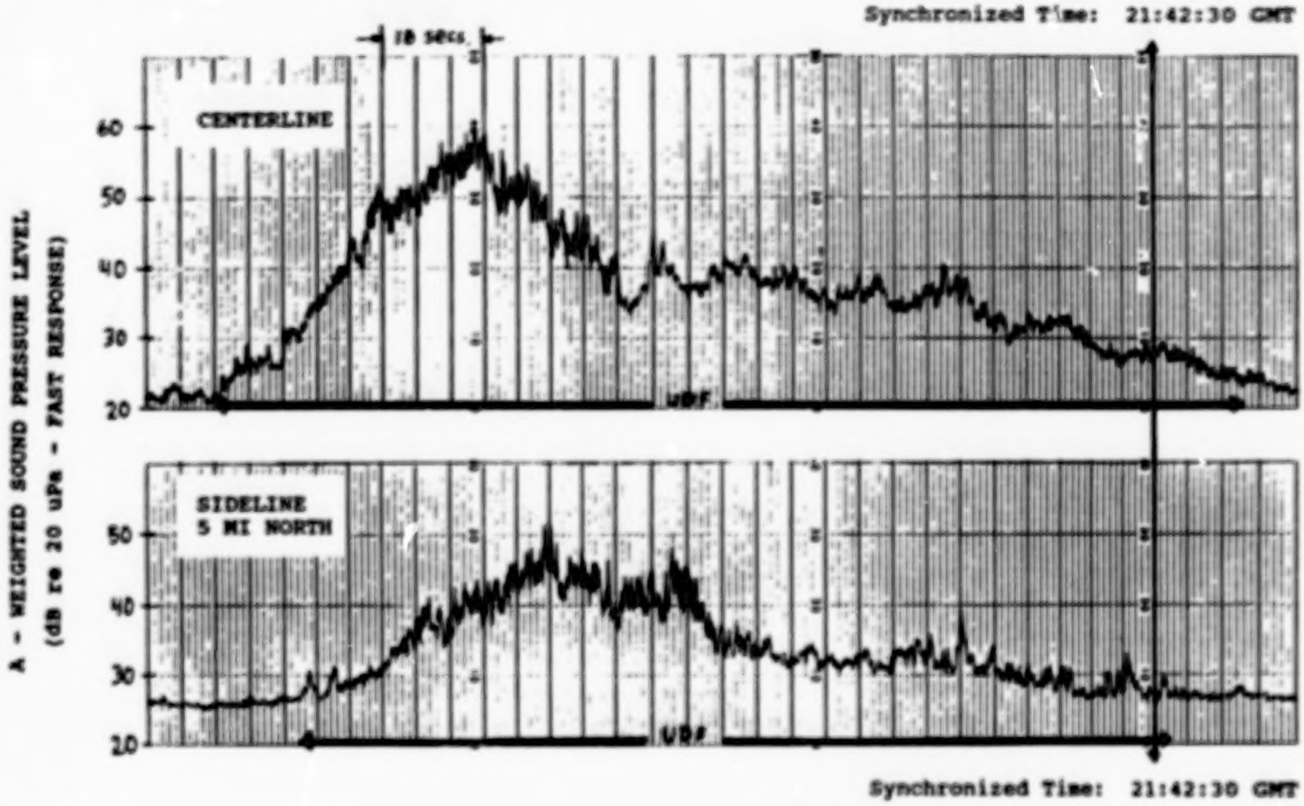


FIG. 3 SYNCHRONIZED NOISE LEVEL TIME-HISTORIES
EN ROUTE NOISE - WHITE SANDS, NM
Event 103 4/4/89
30kft. AGL, 0.7 MACH, 90% SHP, 800 fps

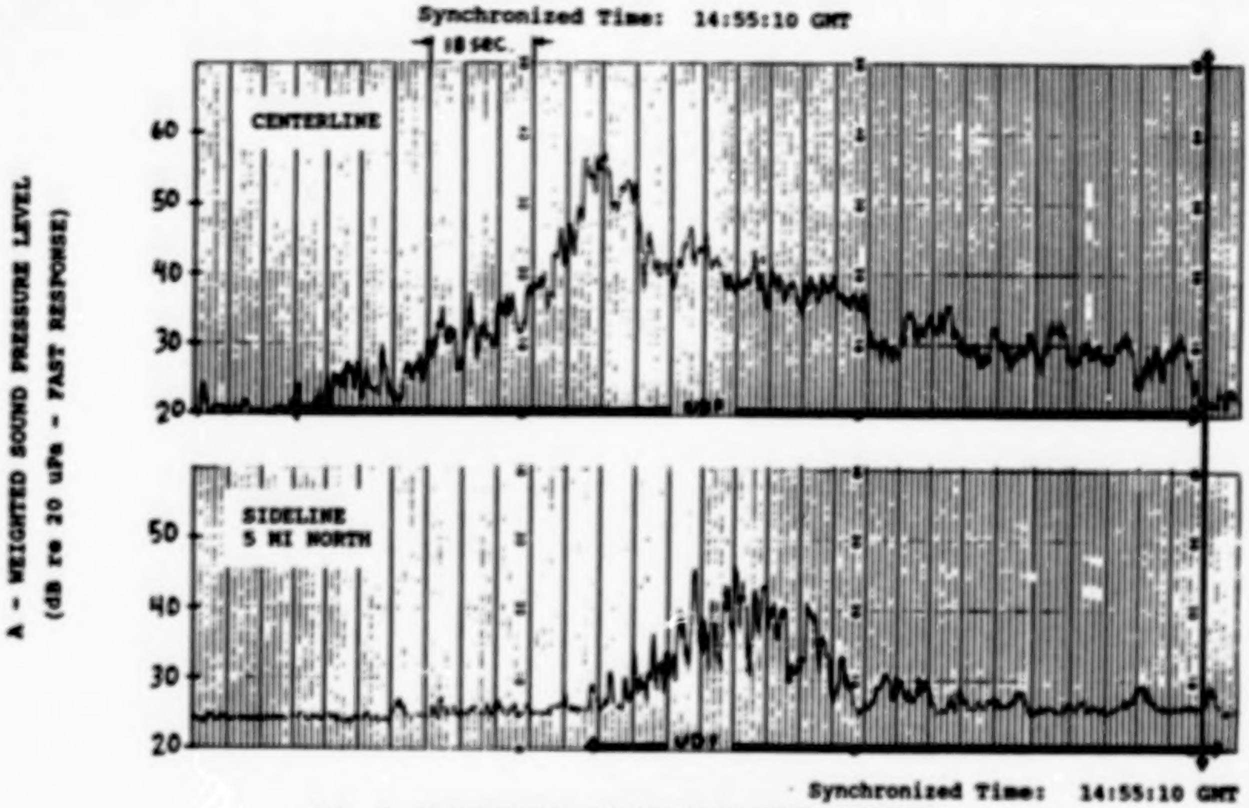


FIG. 4 SYNCHRONIZED NOISE LEVEL TIME-HISTORIES
EN ROUTE NOISE - WHITE SANDS, NM
Event 206 4/5/89
15kft. AGL, 0.7 MACH, 90% SHP, 800 fps

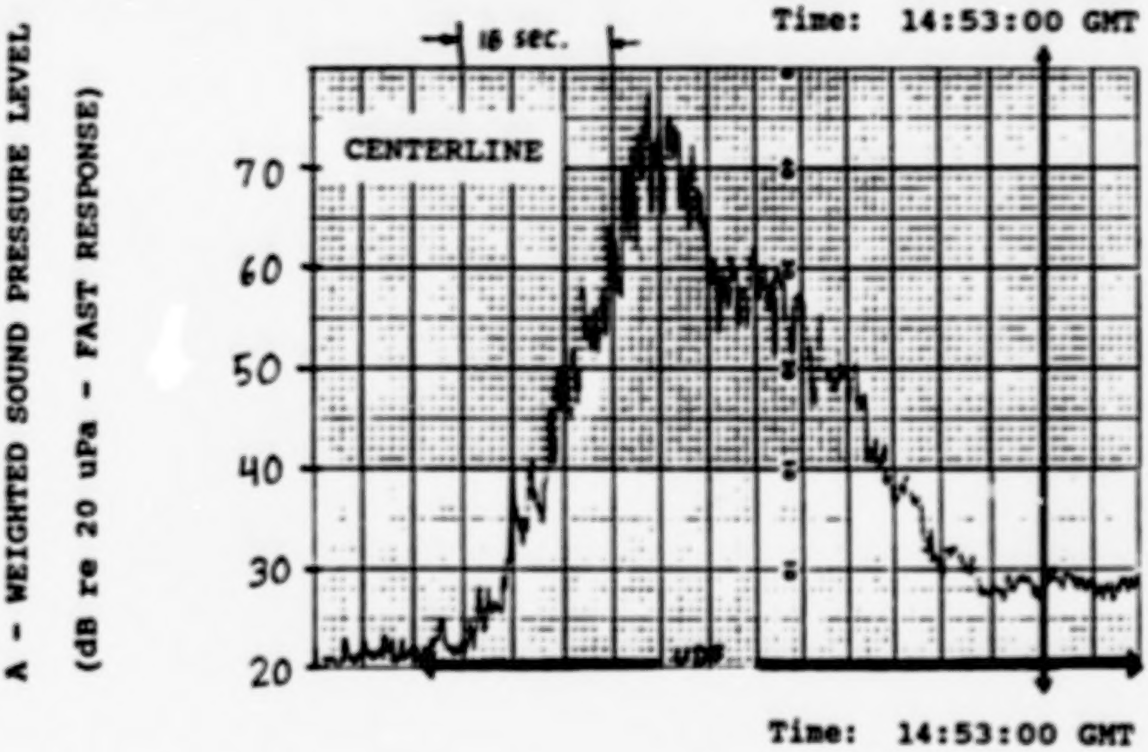


FIG. 5 NOISE LEVEL TIME-HISTORIES
EN ROUTE NOISE - WHITE SANDS, NM
Event 502 4/6/89
2kft. AGL, 0.5 MACH, 90% SHP, 800 fps

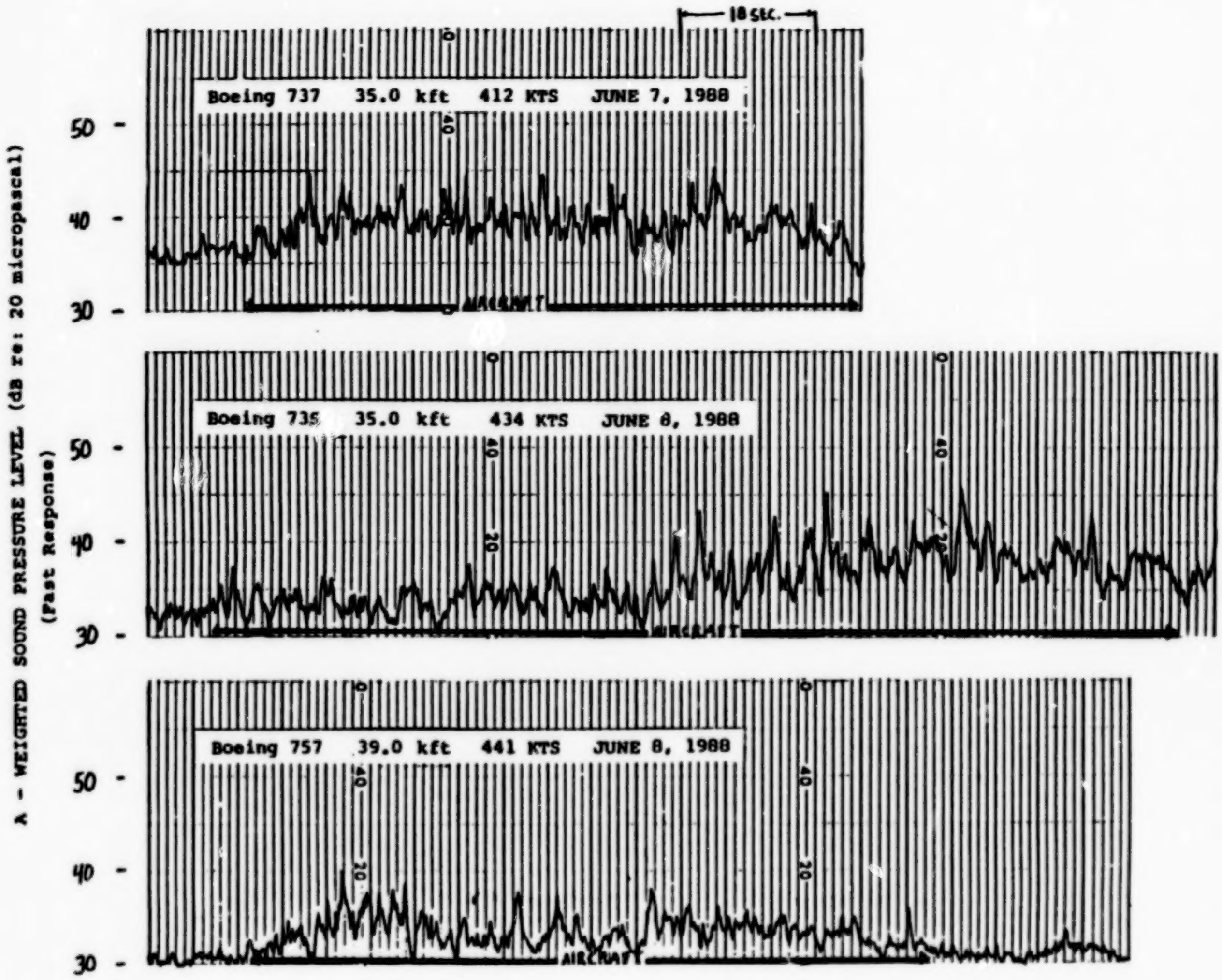


Fig. 6 NOISE LEVEL TIME - HISTORIES

ENROUTE AIRCRAFT NOISE DATA

GORDONSVILLE , VA.

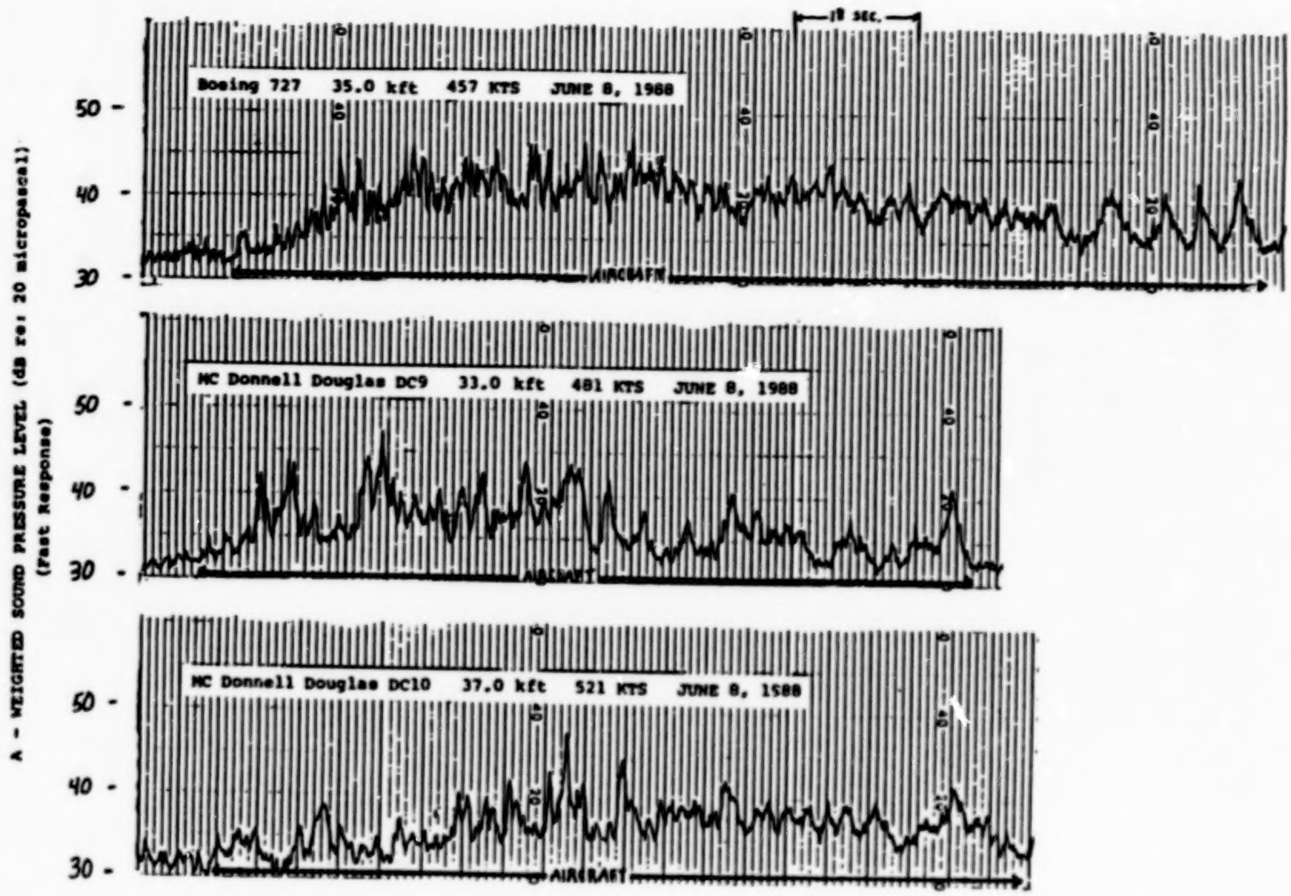


Fig. 7 - NOISE LEVEL TIME - HISTORIES

EN ROUTE AIRCRAFT NOISE DATA

GORDONSVILLE, VA.

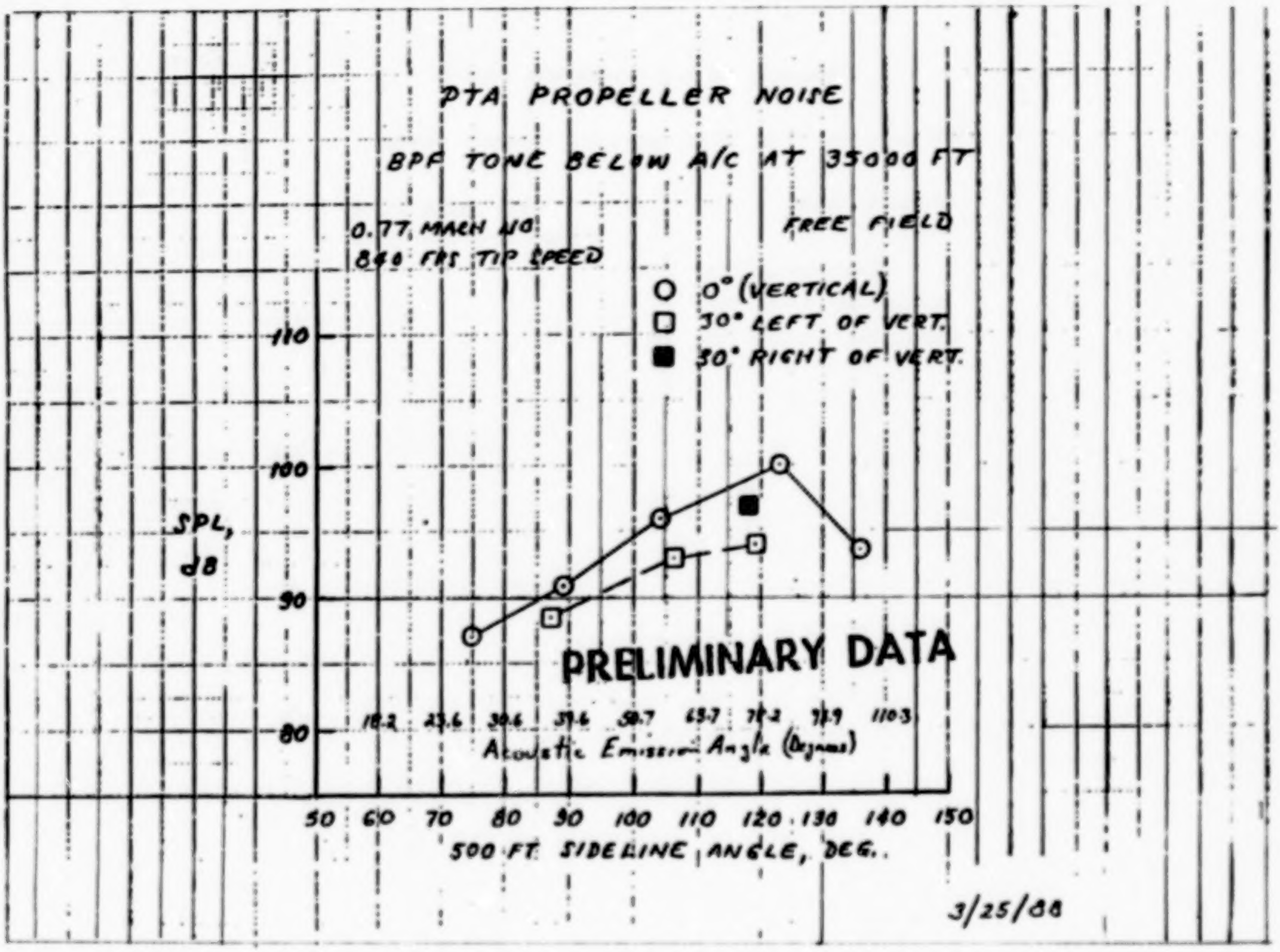


Fig. 8 - Source Noise (NASA Chase Plane)

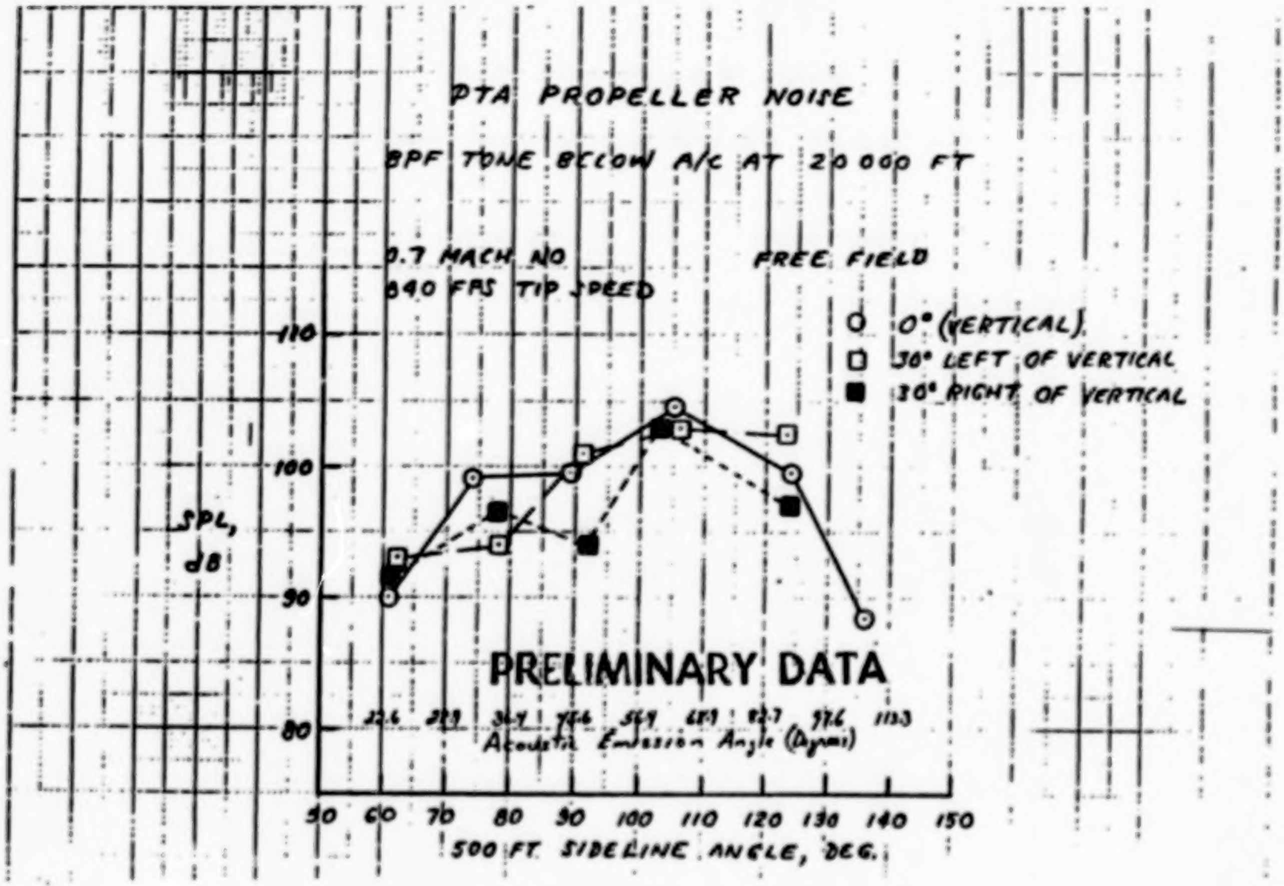


Fig. 9 - Source Noise (NASA Chase Plane)

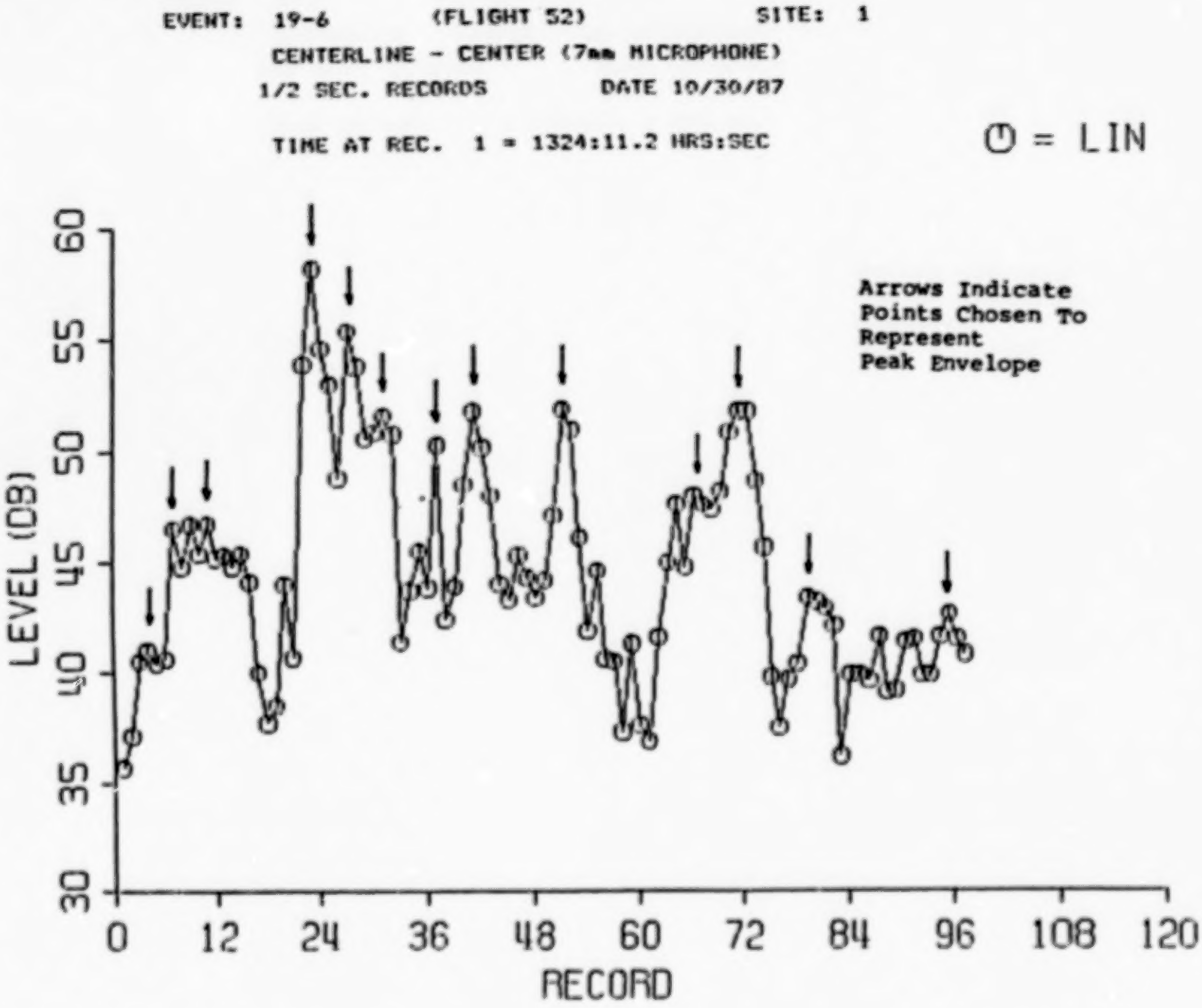
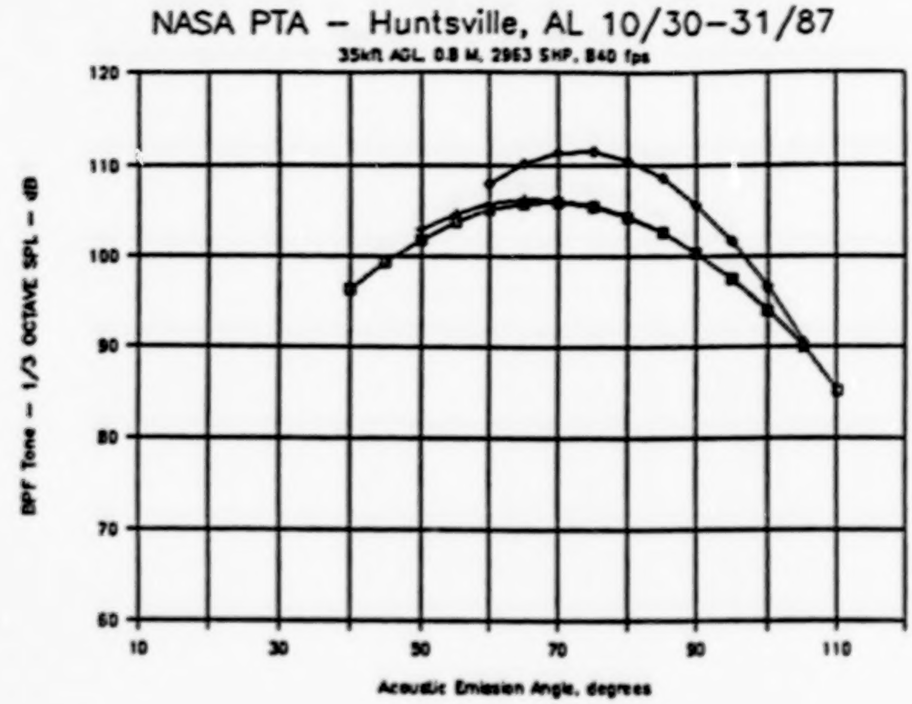
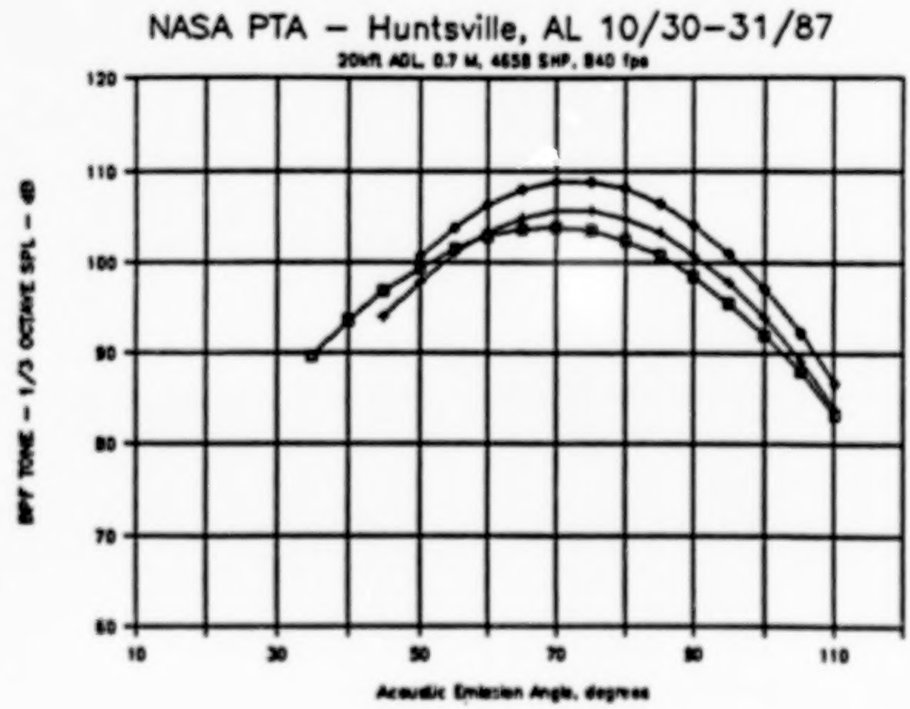


Fig. 10 - Noise Level Time History



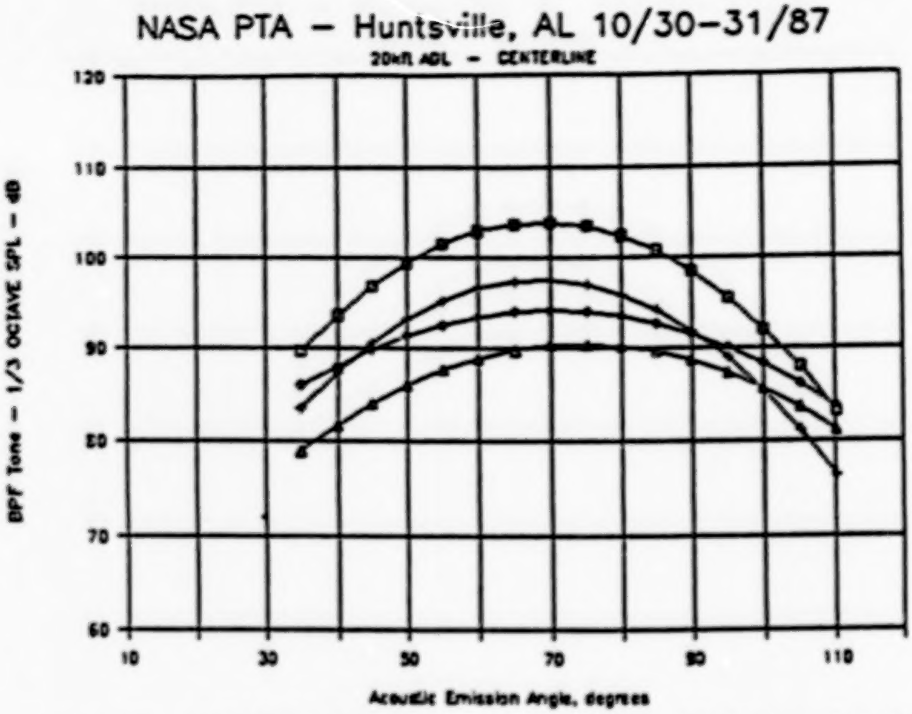
□ CENTERLINE DATA
+ 5 Mi SIDELINE DATA ◇ 10 Mi SIDELINE DATA

FIGURE 11 CALCULATED SOURCE NOISE



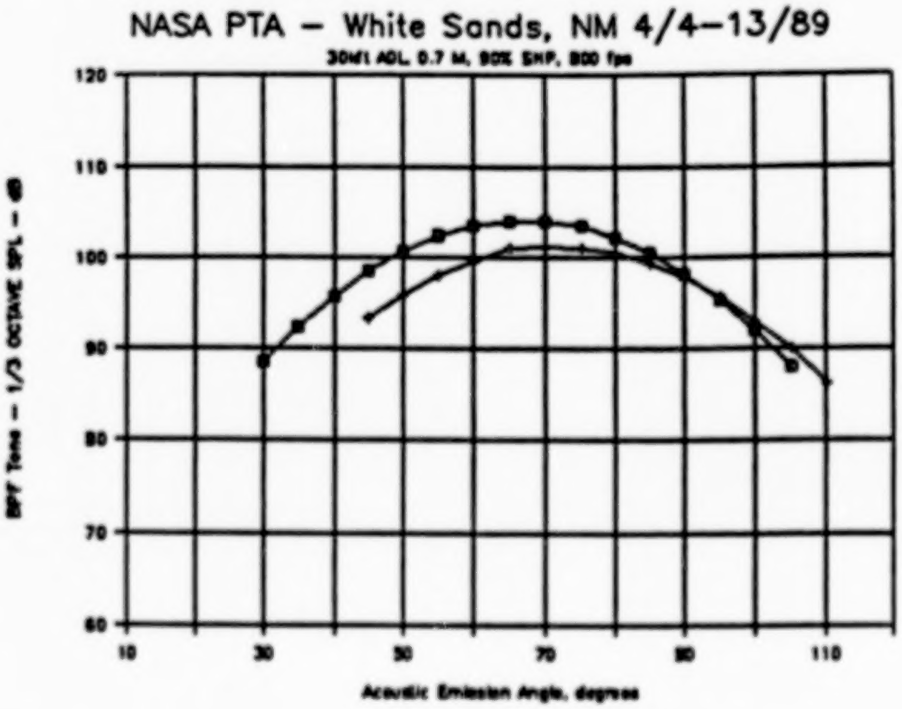
□ CENTERLINE DATA
+ 5 Mi SIDELINE DATA ◇ 10 Mi SIDELINE DATA

FIGURE 12 CALCULATED SOURCE NOISE



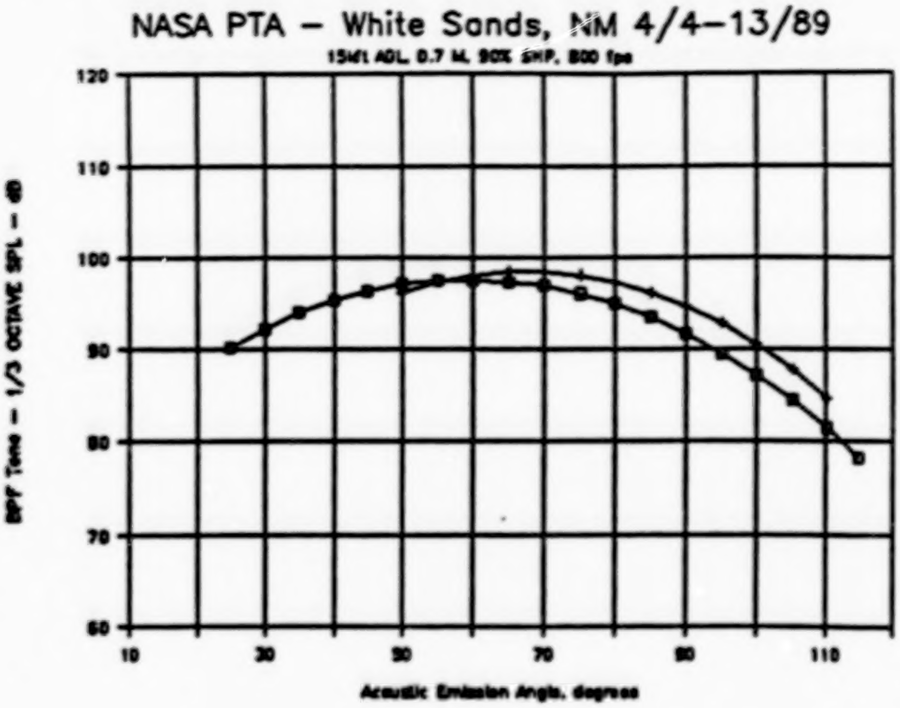
□ 0.7M, 4658 SHP, 840 fps ✚ 0.7M, 3853 SHP, 840 fps
◇ 0.7M, 3853 SHP, 700 fps ▲ 0.7M, 3853 SHP, 620 fps

FIGURE 13 CALCULATED SOURCE NOISE



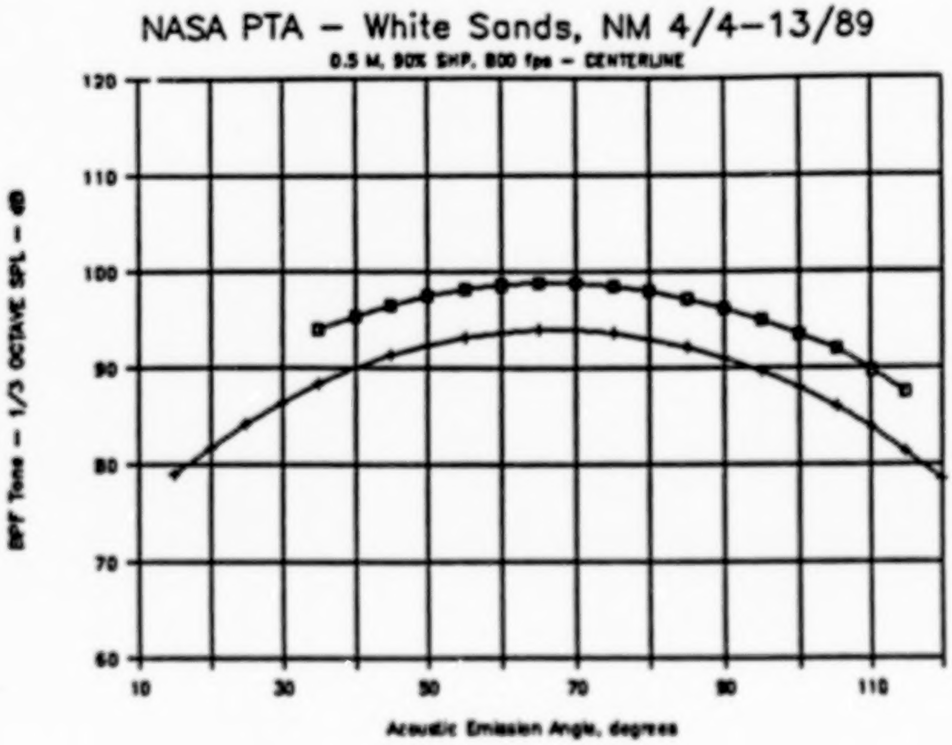
□ CENTERLINE DATA ✚ 5 Mi SIDELINE DATA

FIGURE 14 CALCULATED SOURCE NOISE



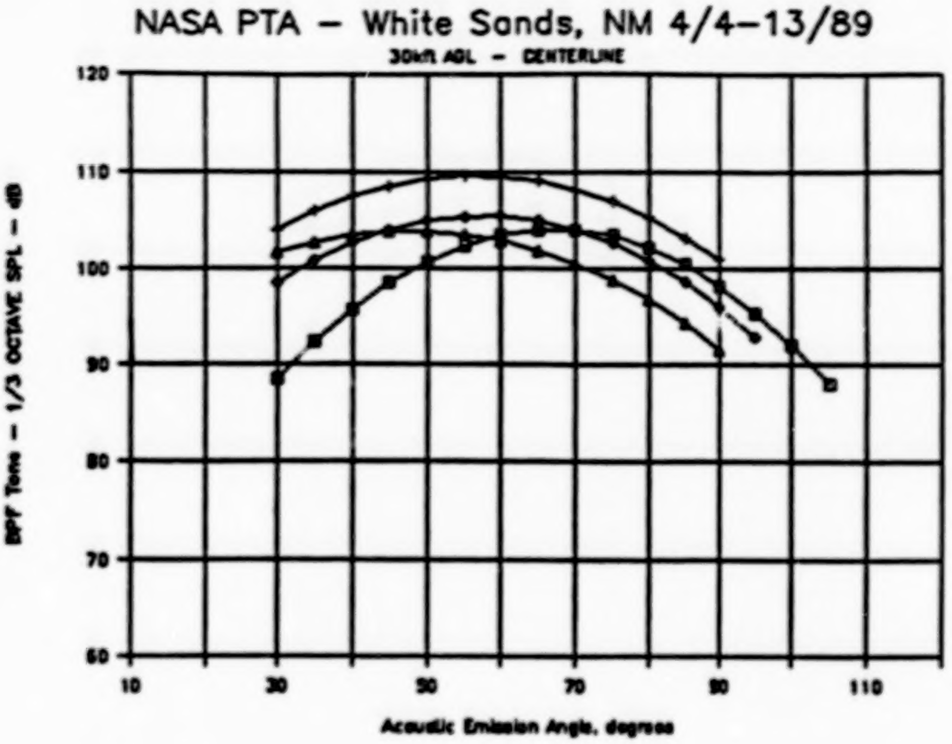
□ CENTERLINE DATA + 5 Mi SIDELINE DATA

FIGURE 15 CALCULATED SOURCE NOISE



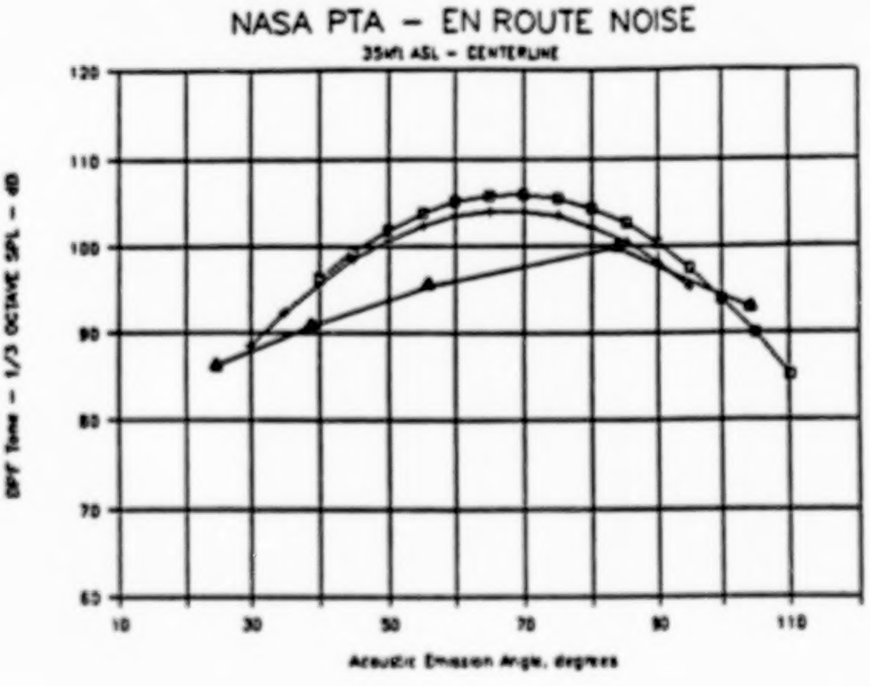
□ 15kft AGL + 2kft AGL

FIGURE 16 NOISE SOURCE COMPARISON



□ 0.7M, 90% SHP, 800 fps
◇ 0.7M, 90% SHP, 700 fps
✚ 0.77M, 100% SHP, 840 fps
▲ 0.7M, 90% SHP, 620 fps

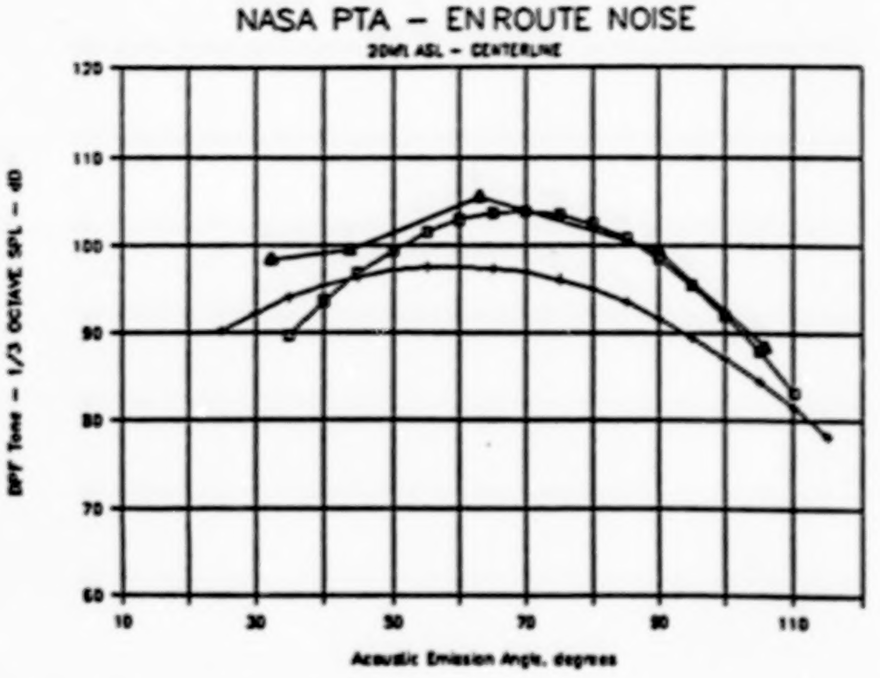
FIGURE 17 CALCULATED SOURCE NOISE



Calculated Source Noise:
□ Alabama 35kft AGL, 0.8 Mach, 2963 SHP, 840 fps, 10/87
✚ New Mexico 30kft AGL, 0.7 Mach, 90% SHP, 800 fps, 04/89

Measured Source Noise :
▲ Alabama 35kft AGL, 0.77 Mach, 2963 SHP, 840 fps, 10/87

FIGURE 18 NOISE SOURCE COMPARISON

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    Calculated Source Noise:
□  Alabama    20kft AGL, 0.7 Mach, 4658 SHP, 840 fps, 10/87
+  New Mexico 15kft AGL, 0.7 Mach, 90%  SHP, 800 fps, 04/89

    Measured Source Noise  :
▲  Alabama    20kft AGL, 0.7 Mach, 4658 SHP, 840 fps, 10/87
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FIGURE 19 CALCULATED SOURCE NOISE

REPORT OF TESTS: EN ROUTE NOISE OF TURBOPROP AIRCRAFT AND THEIR ACCEPTABILITY

Wolf Held
Noise Abatement Commissioner,
The Hessian Ministry for Economics and Technology,
Frankfurt, Federal Republic of Germany

The Noise Abatement Commissioner
of the Hessian Ministry of
Economics and Technology

Frankfurt, 16.08. 1989
he/dh

The development of propfan-powered aircraft has been observed with great interest by the "Association of European Noise Abatement Commissioners" during the past few years.

From various sources it became obvious that during cruise, aircraft with such powerplants (which actually are a renaissance of propellers) cause a noise clearly perceivable on the ground.

We recognize that future aircraft noise might not only annoy the population in the vicinity of airports, but could also be disturbing underneath the network of airways. From the attached map you can see very well the dense network of airways over Central Europe which cannot at all be compared with that of the United States with its large open spaces. (1-5)

The second problem confronting us is the audible frequency spectrum of the propfan powerplants with their relatively high tip speeds. With our present knowledge the expected frequency peak is around 300-200 cycles per second (cps), (graph GE, graph P & W UHB). (6,7)

Primarily, aircraft noise is measured in dB (A) (A-weighted sound pressure level) in Europe. In the range of 300-200 cps about 5-9 dB are deamplified through the A-weighting; in the range of 100 cps it is about 18 dB (s. att.). Through the A-weighting the sensibility of the human ear is considered physiologically; however, it does not consider the psychological part which is not to be neglected, in particular with the extremely disturbing "tone" in the range of 100 cps of present propellers. The deamplification of around 18 dB in the range of 100 cps is the reason for nonregistration of turboprop aircraft at our noise monitoring points. Although turboprop aircraft actually produce around 75 dB as the graph shows (page 118 DLR), they are only "registered" around 60 dB (A). (8,9)

I am very well aware that aircraft traffic is not possible without sound as a consequence. Therefore, jointly, with my European colleagues, I have sought ways in which information should be given to the engine-producing industry to show a limit of "acceptance" of en route noise by a non-A-weighted dB-value.

The only possibility for us to demonstrate a "limit" was the recording of en route noise of two turboprop aircraft which are frequently flown in Europe and which are considered acceptable noisewise en route, even in quiet areas. The aircraft in question are "Metroliner III" with Garret TPE 331-11U-612G engines, 4-blade propeller, and "Fokker F 50" with P & W.PW 125 B-engines and 6-blade propeller. Concerning the number of propeller blades, there is a certain similarity between F 50 and propfan.

We highly appreciated that Frankfurt Airport authorities agreed to finance a small test program since "public authorities" don't have any funds for such programs.

In September 1988 the preparations for the test flights were started. The test had to be postponed on short notice eight times due to meteorological reasons. On April 30, 1989 the program was realized under acceptable conditions.

I have provided the NASA Langley Research Center with a report of the DLR, Braunschweig (Deutsche Forschungsanstalt für Luftund Raumfahrt) composed by Dr. Dobzinsky and a report of the Hessische Landesanstalt für Umwelt, Wiesbaden, composed by Dipl.-Ing. Müller.

Not being an acoustic expert, I am not in a position to either comment on these reports in detail or to discuss them on a scientific basis. However, let me make the following remarks:

The "sound" emitted from both test aircraft is the absolute limit of acceptance for Europe. Today a turbofan engine is measured with around 53 dB(A) on the ground (graph MD-UHB). The peak of frequency (without this clearly perceivable "tone") is at 200 cps. Under consideration of A-weighting this is around 62 dB. Assuming that the peak frequency of propfan is around 300-200 cps (as shown before) 62 dB or 53 dB(A) should not be exceeded (same as with the turbofan). (10)

Following are the dB-max.-readings of the test-flights:

<u>DLR</u>	Metro III	around 66 dB
	F 50	around 63 dB
<u>Hessische Landesanstalt für Umwelt</u>	Metro III	around 69 dB
	F 50	around 66 dB

(tabulation DLR:page 76,77,95 and Hessische Landesanstalt: page 133). (11,12/12a)
Although the dB(A)-readings with 46-48 dB(A) are clearly below those of the turbofan with 53 dB(A), the actual disturbance of the propeller with its clear "tone" has to be equated with that of turbofan.

Let me point out that this test cannot be considered as a scientifically based investigation. The results, however, prove that the en route noise measured is the absolute limit of acceptance for the population.

We shall present a tape recording of the DLR Braunschweig. At the outset the tape has a calibration tone of 94 dB(A) with 1,000 c p s. The recordings were made in a rather quiet spot on the premises of an agriculturally used area. Details can be gathered from the attached reports. The singing of birds (nightingale) as well as the barking of a dog which is to be heard on the tape can be taken as a rough comparison between engine and environment sound.

The recordings of the overflights show "fluctuations" in the range of up to 15 dB, which probably are due to propeller speed fluctuations of both Metro III and of F 50 (DLR att. II #5). (13,14)

In my opinion it must be the task of the engine/propeller industry to reach a most exact possible prop synchronization. Through these "fluctuations" the unpleasant 100 cps.-sound is still intensified.

As to my present knowledge, aircraft equipped with profan powerplants are to be certified as per the criteria of ICAO Annex 16, Chapter III re. FAR 36, Stage 3.

The climbout diagram of METRO III (s. att.) reflects a dominant-band sound pressure level of about 75 dB at an immission point underneath the flight track at an altitude of 9,000'. (9)

This is intended to direct attention to the development of the situation for the time after the first "Production Engine" will be tested.

Let me close my comments with the request to consider them a general contribution of a pilot and Noise Abatement Commissioner. Furthermore, I want to point out that neither my European colleagues nor I have the intention to either obstruct air traffic or to prevent the introduction of new techniques, but we feel that increasing air traffic and new techniques will be advantageous and beneficial to the human being; however, these advantages must by no means result in an increase of aircraft noise and air pollution.

Further details can be collected from the attached reports of DLR and Hessische Landesanstalt für Umwelt.

Thank you very much for your kind attention.

Der Fluglärmschutzbeauftragte des Hessischen Ministeriums für Wirtschaft und Technik

Frankfurt, 15. 08. 1989
he/dh

Die "Association of European Noise Abatement Commissioners" hat in den vergangenen Jahren mit sehr großem Interesse die Entwicklung der Prop-Fan-Engines verfolgt.

Informationen, die aus den unterschiedlichsten Quellen kamen, konnte entnommen werden, daß diese Triebwerke - die quasi eine Renaissance des Propellers darstellen - im Reiseflug einen am Boden deutlich wahrzunehmenden Lärm abstrahlen.

Die Möglichkeit, in Zukunft Fluglärm nicht nur in der Nähe von Flughäfen anzutreffen, sondern auch unter Luftstraßen, hat uns aufmerksam gemacht. Sie können auf dieser Karte (vergl. Anlage) Mitteleuropa und das dichte Netz von Luftstraßen sehen. Sie werden feststellen, daß die Dichte des Luftstraßennetzes kaum mit dem der USA verglichen werden kann, wo am Himmel deutlich mehr Platz ist. 1-5

Das zweite Problem, das sich uns stellte, war die Frage nach den Frequenzen der Geräusche, die das Prop-Fan-Triebwerk emittieren wird. Die Spitzen dürften nach unserer heutigen Kenntnis im Bereich von 300 - 200 Hz liegen. (Bild GE, Bild P & W UHB). 6,7

Fluglärm wird in Europa vorzugsweise in dB(A) gemessen. Die A-Bewertung unterdrückt im Bereich von 300 - 200 Hz 5 - 9 dB, im Bereich 100 Hz rund 18 dB (vergl. Anlage). Die A-Bewertung berücksichtigt die Empfindlichkeit des menschlichen Ohres nach physiologischen Gesichtspunkten. Sie berücksichtigt jedoch nicht die psychologische Seite, die nicht vergessen werden darf, wenn - wie bei den heute gebräuchlichen Propellern - bei ca. 100 Hz ein ausgeprägter "Ton" zu finden ist, den man überproportional deutlich wahrnimmt. Durch die Unterdrückung von rund 18 dB im 100-Hz-Bereich werden Turbo-Prop-Flugzeuge an unseren Noise Monitoring Points nicht registriert. Obwohl sie, wie das Bild zeigt, (S. 47 DLR) rund 75 dB produzieren, werden sie nur mit rund 60 dB(A) "gemessen". 8/9

Mir ist klar, daß Luftverkehr nicht ohne Geräusch betrieben werden kann. Deshalb habe ich mit meinen europäischen Kollegen überlegt, welche Informationen den Triebwerksherstellern gegeben werden müssen in Gestalt eines A-bewerteten Dezibelwertes, der eine Grenze der "Akzeptanz" des enroute-noise in etwa aufzeigt.

Als einzige Möglichkeit, einen "Grenzwert" zu nennen, sahen wir die Aufzeichnung von enroute-noise von zwei Turbo-Prop-Flugzeugen, die in Europa häufig geflogen werden und die als "akzeptabel" im Reiseflug, auch in ruhigen Gegenden, angesehen werden können. Es handelt sich einmal um den "Metroliner III" mit Garett TPE 331-11U-612G-Triebwerken, 4-Blatt-Propeller und die "Fokker F

(German version is unedited)

50" mit P & W.PW 125 B-Triebwerken und 6-Blatt-Propeller. Bei der F 50 ist, was die Zahl der Propellerblätter betrifft, eine gewisse Ähnlichkeit mit dem Prop-Fan gegeben.

Die Flughafen Frankfurt/Main Aktiengesellschaft hat sich dankenswerterweise bereiterklärt, ein kleines Testprogramm zu finanzieren, da in den Kassen der "öffentlichen Hände" für Untersuchungen dieser Art kein Geld vorhanden ist.

Die Vorbereitungen für die Testflüge begannen im September 1988. Die Testflüge mußten aus meteorologischen Gründen achtmal kurzfristig abgesagt werden. Am 30. April 1989 konnte dann unter akzeptablen Bedingungen das Programm durchgeführt werden.

Ich habe dem Langley Research Center der NASA jeweils einen Bericht der DLR Braunschweig (Deutsche Forschungsanstalt für Luft- und Raumfahrt), verfaßt von Herrn Dr. Dobzinsky und der Hessischen Landesanstalt für Umwelt, Wiesbaden, verfaßt von Herrn Dipl.-Ing. Müller, übergeben.

Ich bin kein Akustiker und kann deshalb diese Berichte nicht im Detail kommentieren und wissenschaftlich diskutieren. Folgende Anmerkungen möchte ich jedoch machen:

Die von beiden Testflügen emittierten Geräusche stellen für Europa die äußerste Grenze der Akzeptanz dar. Ein Turbo-Fan-Triebwerk wird heute am Boden mit rd. 53 dB(A) max. gemessen.(Bild MD-UHB). Die Frequenzspitze, wenn auch nicht mit einem deutlichen "Ton", liegt bei 200 Hz. Berücksichtigt man die A-Bewertung, ergeben sich rund 62 dB. Geht man davon aus, daß die Frequenzspitze beim Prop-Fan im Bereich von 300 - 200 Hz liegt, wie vorhin gezeigt, sollten, wie beim Turbo-Fan, 62 dB oder 53 dB(A) nicht überschritten werden. 10

Die bei den Testflügen gemessenen dB-max.-Werte sind:

<u>DLR</u>	Metro III	rund 66 dB
	F 50	rund 63 dB
<u>Hessische Landesanstalt für Umwelt</u>	Metro III	rund 69 dB
	F 50	rund 66 dB

(Tabellen DLR: Seite 20/21 und Hessische Landesanstalt: Seite 2.)
11,12 /12a

Obwohl die dB(A)-Werte mit rund 46 - 48 dB(A) deutlich unter dem Wert des Turbo-Fans mit 53 dB(A) liegen, muß die subjektive Störung, bedingt durch den deutlichen "Ton", beim Propeller mit dem des Turbo-Fans gleichgesetzt werden.

Ich möchte noch betonen, daß dieser Test keine Untersuchung im

streng wissenschaftlichen Sinne sein kann. Die Ergebnisse zeigen jedoch eine Größenordnung des enroute-noise auf, die die subjektiv empfundene Grenze für die Akzeptanz bei der Bevölkerung darstellen dürfte.

Sie hören noch einen Ausschnitt aus der Tonbandaufzeichnung der DLR Braunschweig. Das Band hat am Anfang einen Calibration-Ton von 94 dB(A) bei 1 000 Hz. Die Aufnahmen wurden an einer relativ ruhigen Stelle einer landwirtschaftlich genutzten Fläche aufgenommen. Einzelheiten enthalten die beigefügten Berichte. Die auf Band zu hörenden Vögel (Nachtigall) und das Bellen eines Hundes geben die Möglichkeit eines, wenn auch sehr groben, Vergleiches der Triebwerksgeräusche mit den Umgebungsgeräuschen.

Die Aufzeichnungen der einzelnen Überflüge zeigen mehr oder weniger ausgeprägte "Fluctuations" bis zu 15 dB, die vermutlich durch Schwankungen in der Drehzahl der beiden Triebwerke sowohl bei der Metro III als auch bei der F 50 (DLR-Anlage II # 5) hervorgerufen werden. [13,14]

Es muß nach meiner Ansicht Aufgabe der Triebwerks- Luftschraubenhersteller sein, eine möglichst exakte Prop-Synchronisierung zu erreichen. Die "Fluctuations" verstärken den ohnehin unangenehmen "100-Hz-Ton".

Nach meinem augenblicklichen Kenntnisstand sollen Flugzeuge mit Prop-Fan-Triebwerken nach den Kriterien des ICAO Annex 16, Kap. III, re. FAR 36, Stage 3, zugelassen werden.

Das Diagramm des climb-out der Metro III (vergl. Anlage) zeigt bei einer Flughöhe von rund 9 000 ' unter dem Flugweg ca. 75 dB. [9]

Das soll eine Anregung sein, dieser Situation Aufmerksamkeit zu schenken, wenn die ersten Triebwerke der "Production Engine" in Erprobung gehen.

Ich möchte meine Ausführungen schließen mit der Bitte, sie als allgemeinen Beitrag eines Piloten und Noise Abatement Commissioners zu betrachten. Ferner möchte ich betonen, daß meine europäischen Kollegen und ich unsere Aufgabe nicht so verstehen, daß wir den Luftverkehr behindern oder die Einführung neuer Techniken verhindern wollen. Wir fühlen uns verpflichtet beizutragen, daß ein steigender Luftverkehr und neue Techniken dem Menschen allgemein Vorteile bringen. Diese Vorteile dürfen jedoch nicht mit spürbaren Nachteilen im Umweltbereich, wie einem Anstieg von Fluglärm und Luftverschmutzung, erkauft werden.

Weitere Details können Sie bitte den beiden beigefügten Berichten der DLR und der Hessischen Landesanstalt für Umwelt entnehmen.

Ich bedanke mich für Ihre Aufmerksamkeit.

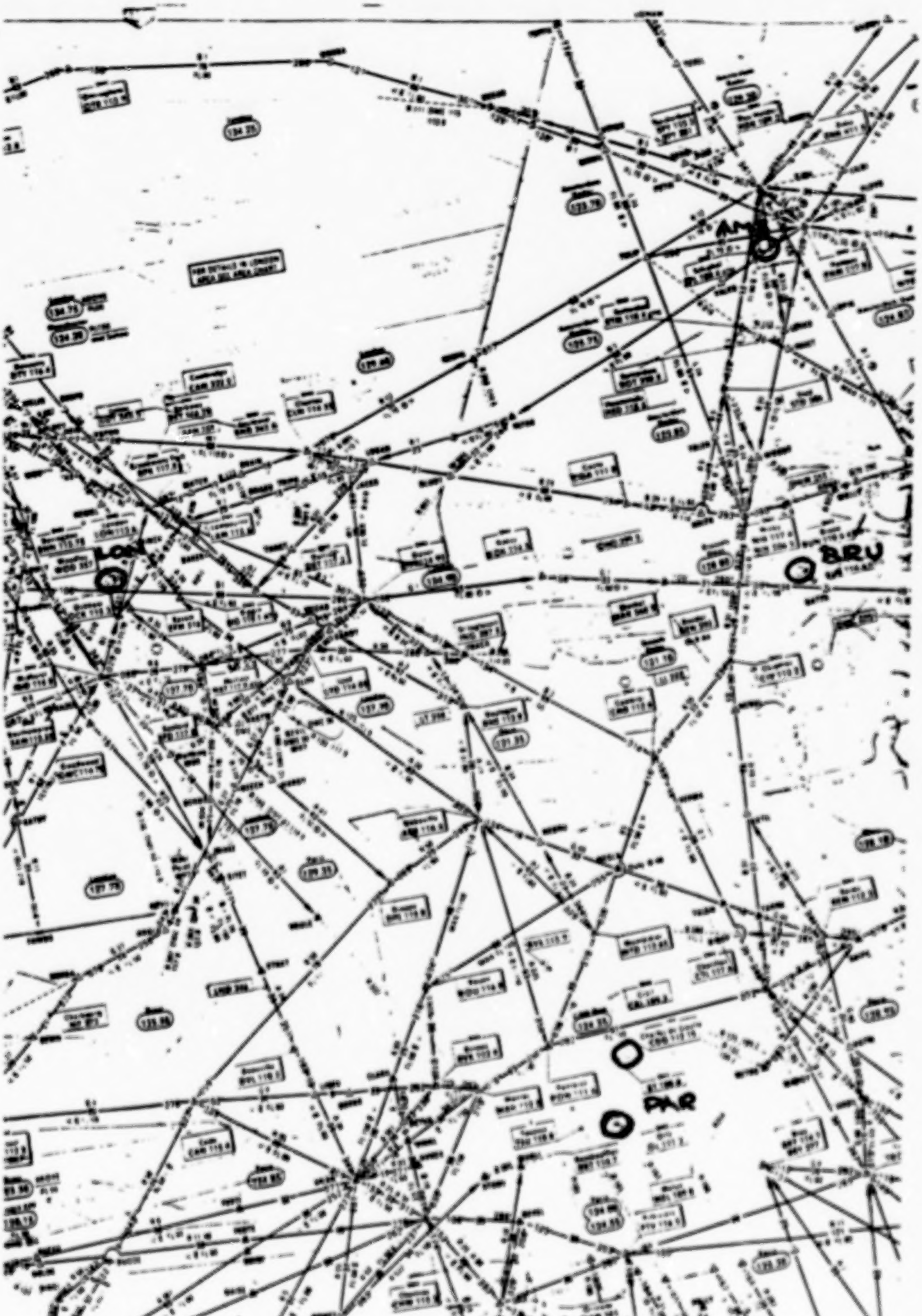

FIGURE 1


HAJ
DUS
FRA
NUE
4000 CROSSINGS PER DAY.
STR
MUC
STRAS-BOURG
BSL
ZRH

FIGURE 2

FIGURE 3

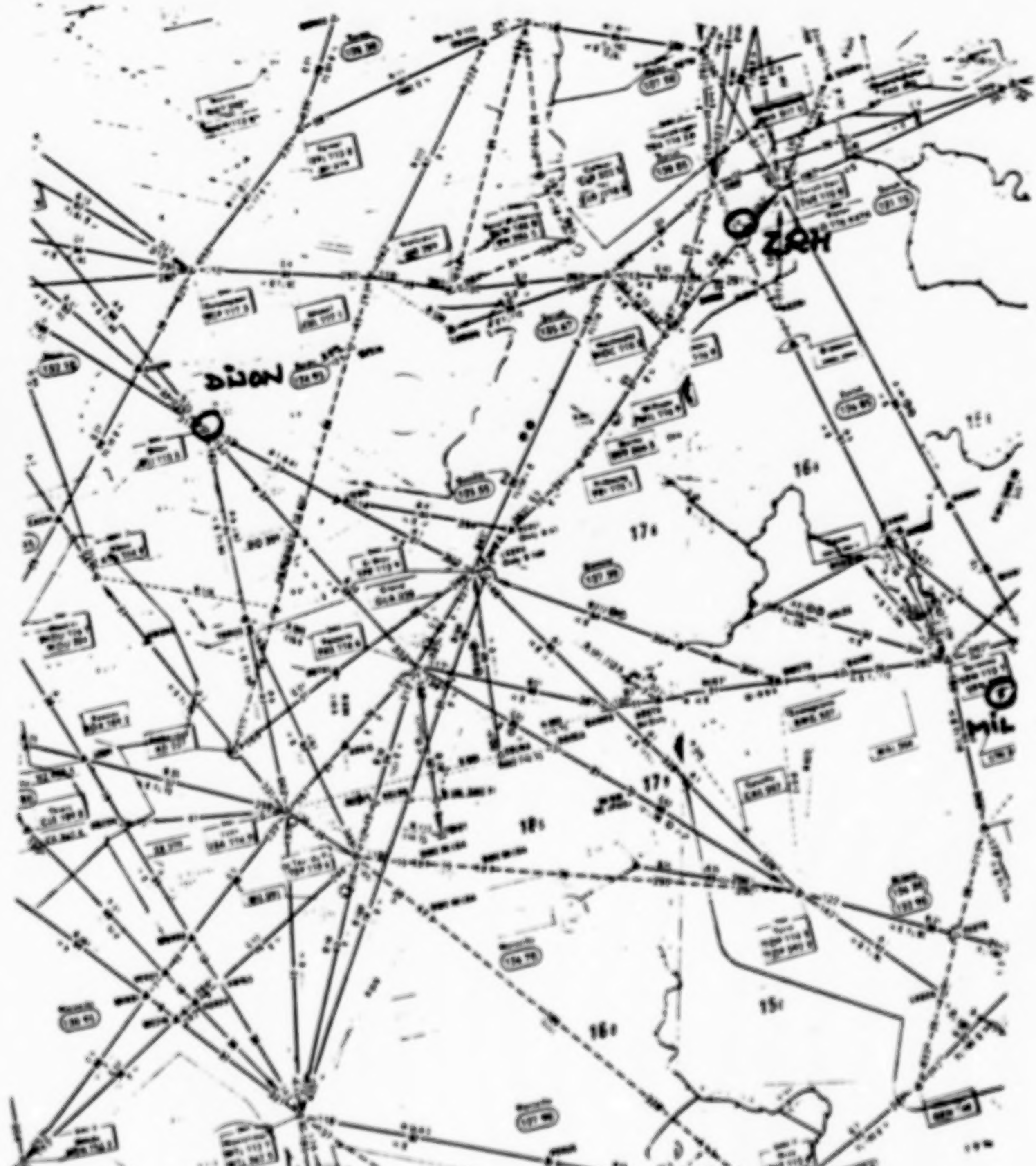

FIGURE 4

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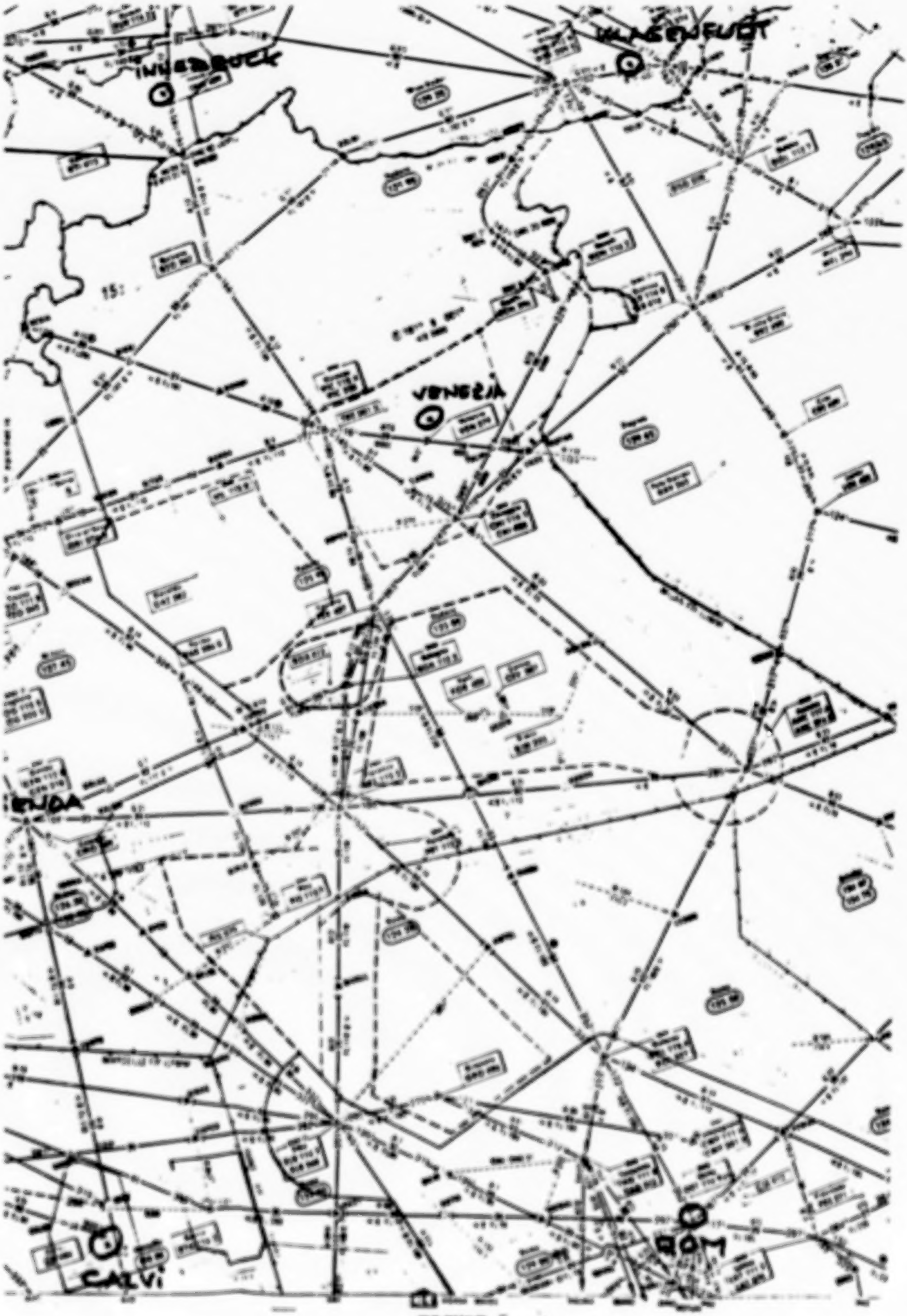
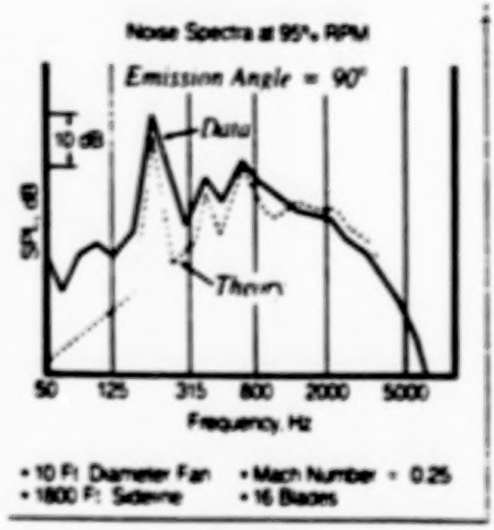


FIGURE 5



GE UDF

FIGURE 6

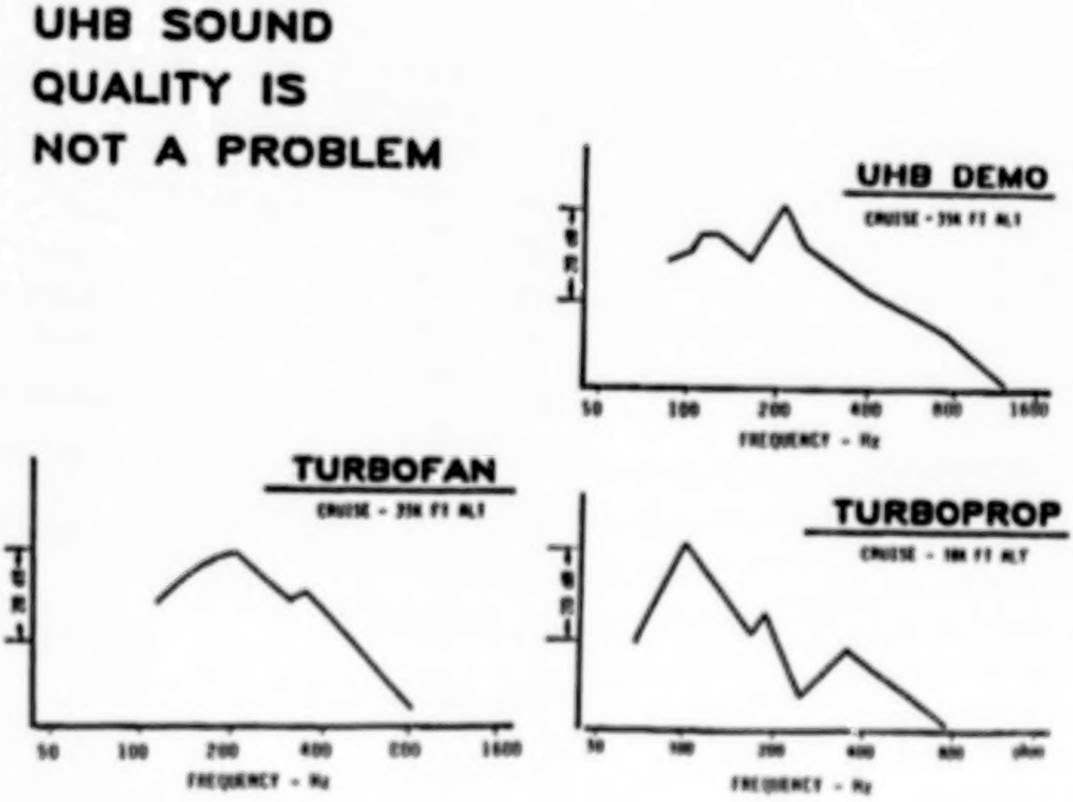
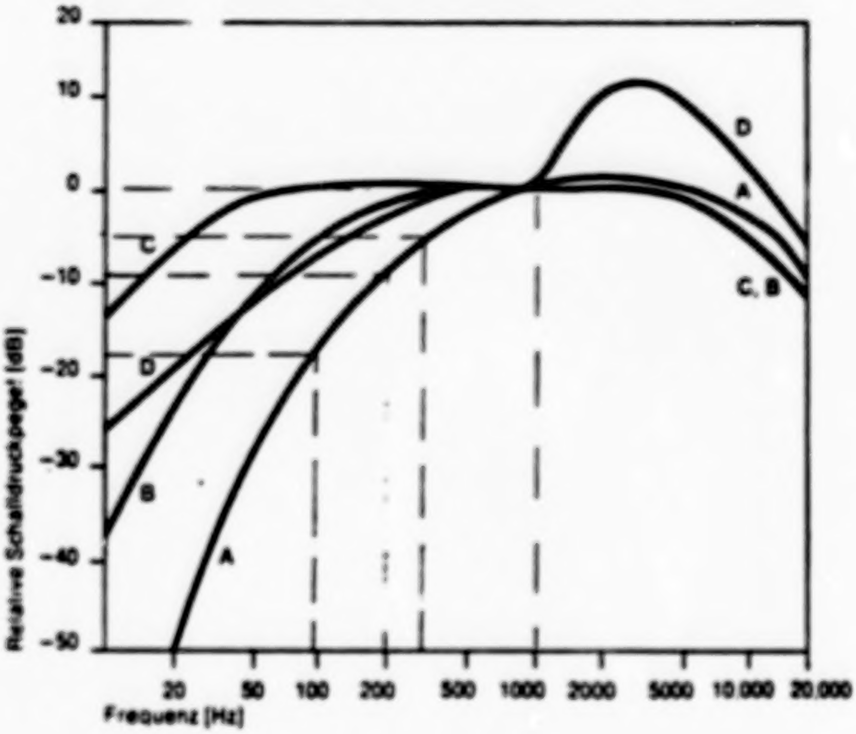


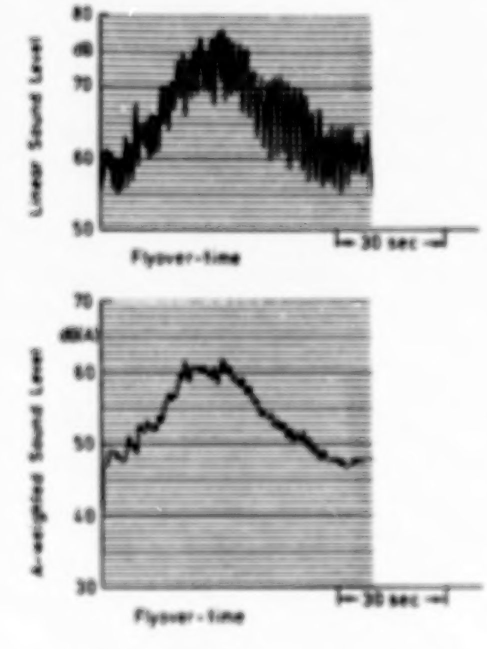
FIGURE 7



Quelle EPH, Criteria Doc. July 27, 1973

FIGURE 8

Type of Aircraft: Metro III Flyover No.: 1
Microphone Position: Ground-board Microphone



As measured overall level time-histories (Metro III climb out)

FIGURE 9

EN ROUTE SOUND COMPARISON FOR AIRPLANE CRUISE OPERATIONS

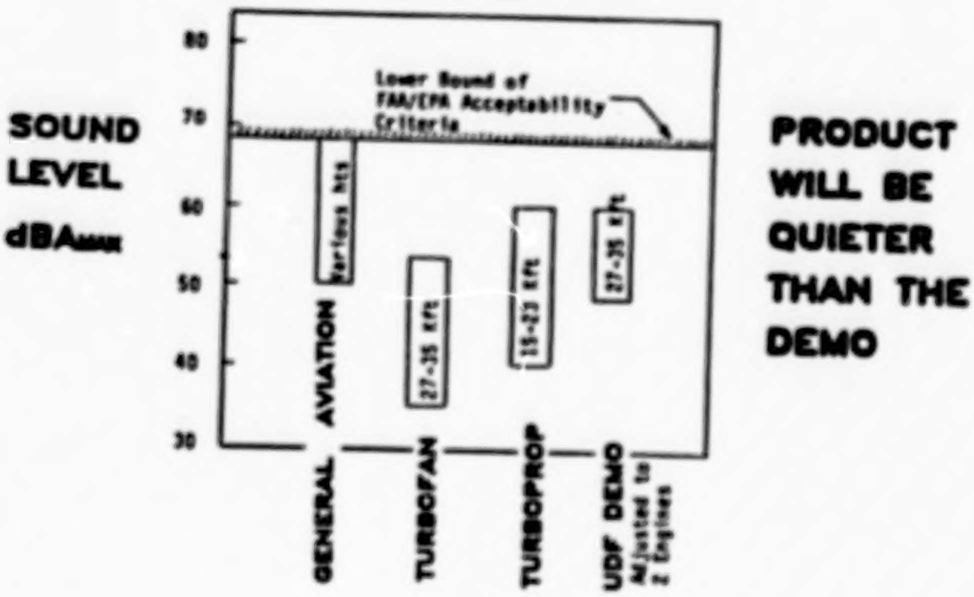


FIGURE 10

En Route Noise Measurement (Frankfurt/Griesheim; 30.4.89)

Aircraft Type: Metro III SA 227
Propeller Diameter = 2.692 m (4 Blades)

Operational Conditions: TAS = 230.0 kts
Propeller Rot. Speed = 1543.3 rpm (BPF = 102.9 Hz)

No.	Flight Height ft	Air Temp. °C	M_{Hel}	$L_{A,max}$ (Slow) dB(A) Ground Mic	$L_{A,max}$ (Slow) dB(A) 1.2 m Mic	L_{max} (Fast) dB Ground Mic	L_{max} (Fast) dB 1.2 m Mic
1*	8000	-	-	61.7	56.9	78.4	74.2
2	17000	-14	0.7675	52.9	48.9	70.3	67.2
3	17000	-14	0.7675	54.1	50.5	72.0	68.5
4	19000	-20	0.7764	50.6	47.5	68.0	65.7
5	19000	-20	0.7764	50.2	47.5	68.1	65.9
6	21000	-26	0.7858	52.1	48.2	68.7	65.9
7	21000	-26	0.7858	49.9	46.0	68.0	64.9
Level Averages (without No. 1)				51.6	48.1	69.2	66.4
Level Differences (Ground -1.2 m)				Δ = 3.5		Δ = 2.8	
Background Noise Levels:				39.0	37.9	54.0	53.0

* Take-off Power Setting

Table Listing of measured maximum overall noise levels from Metro III aircraft fly-overs

FIGURE 11

En Route Noise Measurement (Frankfurt/Griesheim; 30.4.89)

Aircraft Type: Fokker 50
Propeller Diameter = 3.66 m (6 Blades)

Operational Conditions: TAS (Average) = 280.5 kts
Propeller Rot. Speed = 1025.0 rpm (BPF = 102.5 Hz)

No.	Flight Height ft	Air Temp. °C	M_{Hel}	$L_{A,max}$ (Slow) dB(A) Ground Mic	$L_{A,max}$ (Slow) dB(A) 1.2 m Mic	L_{max} (Fast) dB Ground Mic	L_{max} (Fast) dB 1.2 m Mic
8	17000	-14	0.7554	51.0	48.5	67.5	64.4
9	19000	-20	0.7643	53.9	51.1	70.9	68.8
10	19000	-19	0.7628	46.9	43.5	63.7	----
11	21000	-24	0.7704	45.9	43.9	63.0	60.8
12	21000	-24	0.7704	46.6	44.0	63.7	60.3
Level Averages				48.9	46.2	65.8	63.5
Level Differences (Ground -1.2 m)				Δ = 2.7		Δ = 2.3	
Background Noise Levels:				39.0	37.9	54.0	53.0

Table Listing of measured maximum overall noise levels from Fokker 50 aircraft fly-overs

FIGURE 12

Nr.	Flight Level	Maximaler Überflugpegel			
		L_{AS} max |dB(A)|		L_{LinF} max |dB|	
		1,5 m	10 m	1,5 m	10 m
1	Start	62,3	60,5	79,9	79,5
2	170	52,8	49,3	71,6	67,2
3	170	52,8	48,5	71,5	66,9
4	190	52,3	46,6	71	65,7
5	190	50,5	47,5	69	66,8
6	210	52,3	47,6	69,9	63,4
7	210	49,5	47,7	68,1	64,2
8	Start	56,9	55,5	73,4	72,2
9	170	54,2	47,7	71,5	66,5
10	170	49,8	48,2	66,1	62,4
11	190	55,4	48,6	73,9	65,2
12	190	47,6	46,7	65,5	63,8
13	210	46,8	45,2	63,9	62,1
14	210	46,6	42,3	62,5	57,2

Nr. 1-7 METRO III

Nr. 8-14 FOKKER 50

Flight Level 170 = 5182 m
Flight Level 190 = 5791 m
Flight Level 210 = 6401 m

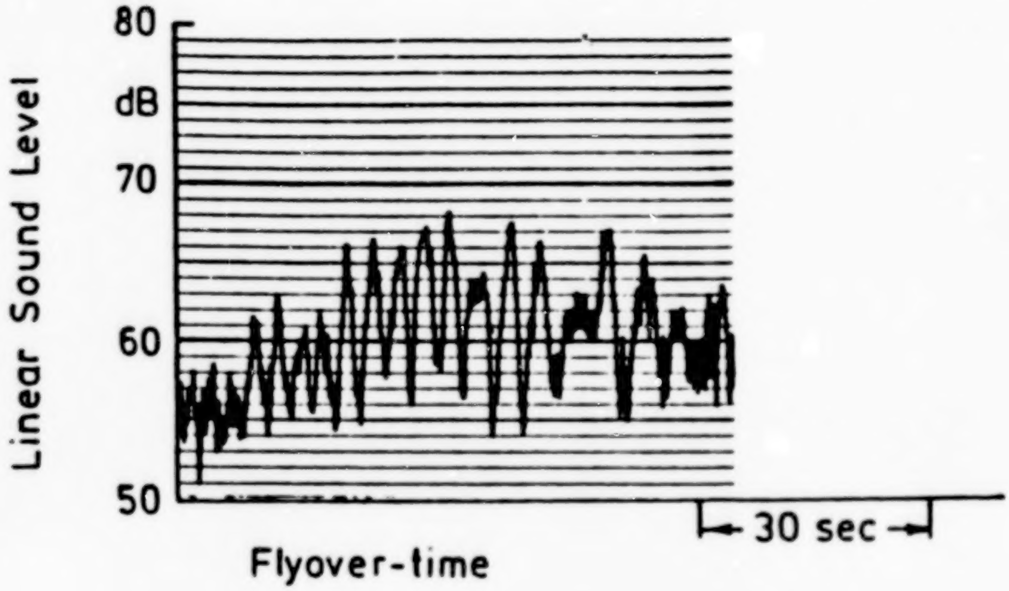
In 10 m Höhe wurden bei allen Überflügen geringere A-Maximalpegel gemessen.

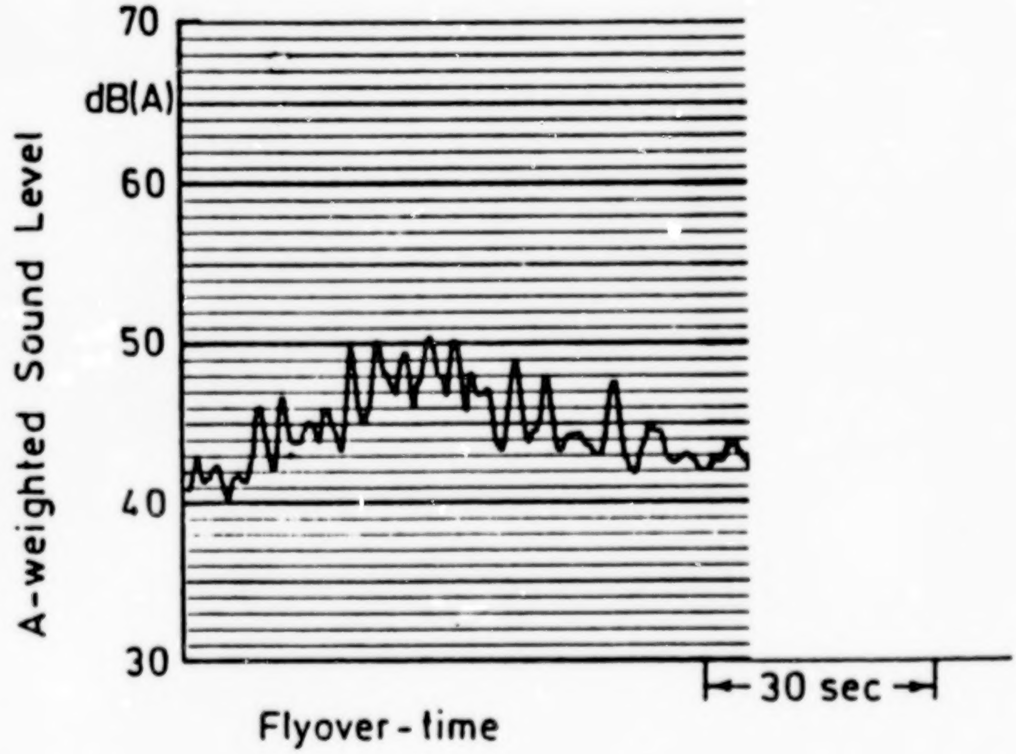
Diese Tatsache bestätigt die Aussagen im Forschungsbericht (DFVLR-FB81-28) der DLR über Interferenzwirkungen durch Bodenreflexion bei Fluglärmmessungen an Propellerflugzeugen. Danach sind bei Verwendung von Meßmikrofonen mit großem Bodenabstand im

FIGURE 12a

Type of Aircraft: Metro III   Flyover No.: 5

Microphone Position: Ground-board Microphone



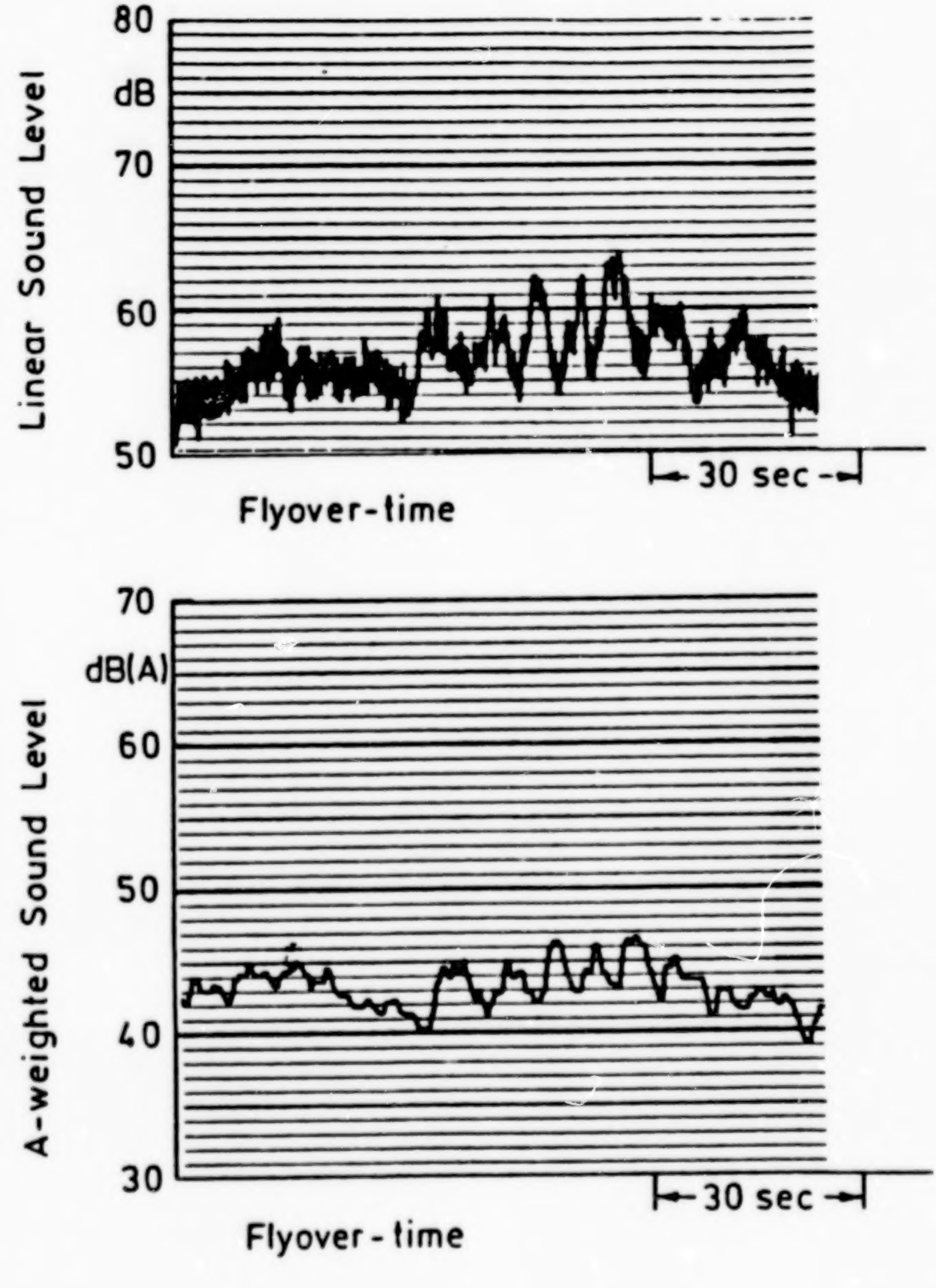


As measured overall level time-histories (Metro III/ No. 5, flight height: 19000 ft)

FIGURE 13

Type of Aircraft: Fokker 50 Flyover No.: 10

Microphone Position: Ground-board Microphone



As measured overall level time-histories (Fokker 50/ No. 10, flight height: 19000 ft)

FIGURE 14

References

Fig. 1-5	Air Navigation Chart ATLAS/DLH
Fig. 6	The Leading Edge, Fall 86, Page 73, GE
Fig. 7	P & W Info to Frankfurt Noise Abatement Commissioner 1988
Fig. 8	DLH, Problems of Noise Abatement Jan. 1981
Fig. 9	DLR Report att.
Fig. 10	MD-Info to Frankfurt Noise Abatement Commissioner Nov. 88
Fig. 11/12	DLR Report att.
Fig. 12a	HLfU Report att.
Fig. 13	DLR Report att.
Fig. 14	DLR Report att.

DATA REPORT: "EN ROUTE" NOISE OF TWO TURBOPROP AIRCRAFT

Werner Dobrzynski

Deutsche Forschungsanstalt für Luft- und Raumfahrt
Forschungsbereich Strömungsmechanik
Institut für Entwurfsaerodynamik
Abteilung Technische Akustik
Flughafen
D-3300 Braunschweig

Braunschweig, im Juni 1989

Institutsleiter:
Dr.-Ing. H. Körner

Verfasser:
Dr.-Ing. W. Dobrzynski

Abteilungsleiter:
Dr.-Ing. H. Heller

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Propellerlärm, Reisefluglärm

Datenbericht: Reisefluglärm von zwei Turboprop-Flugzeugen

Übersicht

Zur Beurteilung des Reisefluglärms künftiger Verkehrsflugzeuge mit Propfanantrieben werden Vergleichsdaten von herkömmlichen Turboprop-Flugzeugen benötigt. Als Beitrag zu einer solchen Datenbank wurden Reisefluglärmmessungen an zwei zweimotorigen Turboprop-Flugzeugen in Flughöhen zwischen 5182 m und 6401 m durchgeführt. Die Geräuschpegel werden zusammen mit den Betriebsdaten der Antriebspropeller und den meteorologischen Umgebungsbedingungen angegeben. Schmalband-Frequenzanalysen zeigen die besonderen Eigenschaften des gemessenen Propellergeräusches, nämlich die Dominanz des Pegels der Propellerdrehklangfundamentalen und das Auftreten von akustischen Schwebungen durch unterschiedliche Drehzahlen der zwei Antriebspropeller.

Propeller Noise, En route Noise

Data Report: "En route" Noise of two Turboprop-Aircraft

Summary

In order to weigh en-route noise immissions originating from future propfan powered aircraft a data base of immission levels from conventional turboprop aircraft is needed. For this reason flyover noise measurements on two twin-engine turboprop aircraft were conducted at flight heights between 17000 ft and 21000 ft. Acoustic data are presented together with propeller operational parameters and environmental meteorological data. Narrowband spectral analyses demonstrate the characteristic features of the measured propeller noise signatures: Noise spectra are dominated by the propeller rotational noise fundamental frequency and pronounced noise beats occur as a consequence of different rotational speeds of the propellers.

Contents

List of symbols

BLN	-	Number of propeller blades
BPF	Hz	Blade passing frequency =(N/60) BLN
f	Hz	Sound frequency
H	m	Flight height
HN	-	Harmonic number
L	dB	Overall sound pressure level
L_A	dB	Overall A-weighted sound pressure level (A-sound level)
M	-	Flight Mach number
M_{Hel}	-	Helical propeller blade-tip Mach number
N	1/min	Propeller rotational speed
p	N/m^2	Sound pressure amplitude
r	m	Distance between sound source and observer
t	sec	Time
t_s	sec	Cycle-time of sound beats
T	°C	Temperature
V	m/s	Flight speed
ω	Hz	Circular frequency $=2\pi f$
θ	deg	Elevation angle

Subscripts

o	-	Reference
max	-	Maximum value

Note: Sound pressure levels are referenced to $p_o=20\,\mu Pa$

1. Introduction

The significant and world wide increase in air-traffic during the last decade has led to a noise nuisance caused by aircraft in cruise, operating at high altitudes. Complaints are reported both from resort areas with inherently low background noise and from areas underneath crowded air-traffic junctions.

The issue of the so called "en route noise" has been raised recently within the Working Groups of the ICAO-Committee on Aircraft Environmental Protection (CAEP). A potential problem is foreseen with the development and introduction of new propfan-powered aircraft within the next few years. In fact, it is the low-frequency harmonic noise signature of such propeller-type propulsion systems which worries the acoustics engineers and administrators alike, who expect an increase in en route noise related complaints.

In the United States the first flyover noise measurements on a propfan powered research type aircraft were recently conducted. In order to check measured noise characteristics in terms of their "annoyance" potential they need to be compared against some adequate reference. An appropriate reference could be the noise characteristics of conventional turboprop-aircraft that have been in operation for many years and are more or less accepted by the public.

The task at hand, therefore, is to define a "level-number" which, in combination with the particular propfan/propeller noise characteristics, would be acceptable as not to further aggravate the present en route noise problem. Since no extensive data base exists for such a comparison, en route noise data from turboprop aircraft must be collected to provide a reference as an acceptable noise limit.

This report presents flyover noise data as measured from two different turboprop aircraft at typical cruising altitudes along with local meteorological and aircraft operational data. The

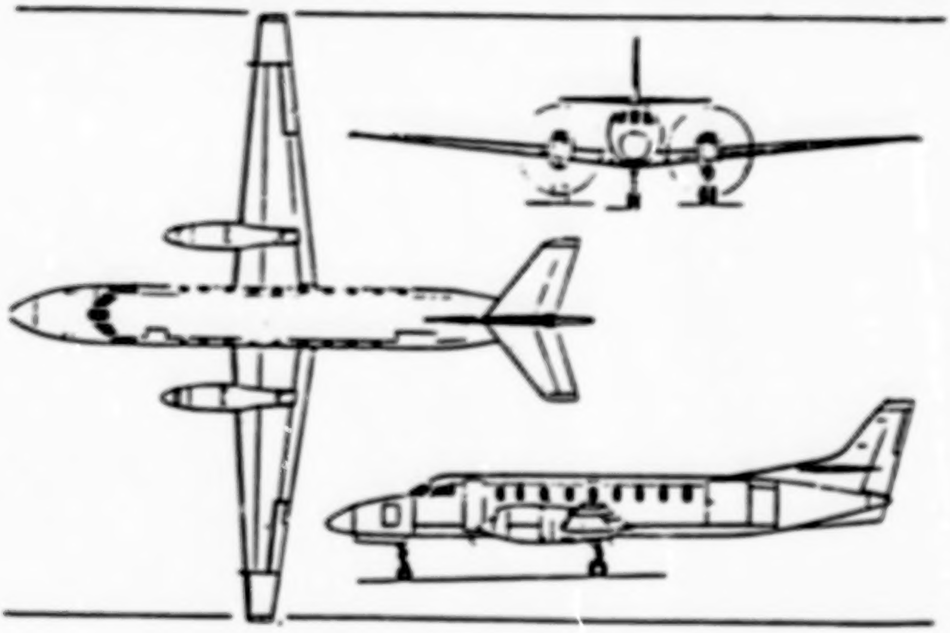


Fig. 1 Fairchild Metro III aircraft

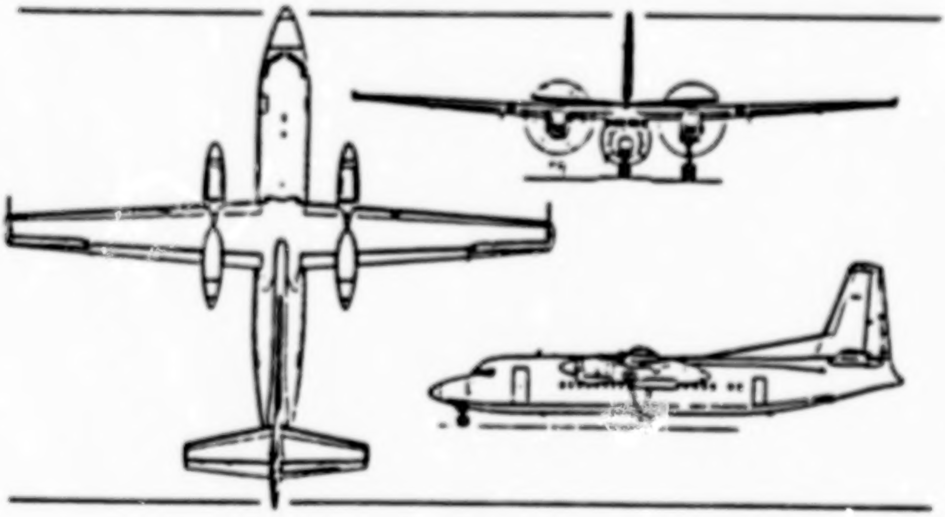


Fig. 2 Fokker 50 aircraft

measurement campaign was initiated and organized by the "Noise Abatement Commissioner of the Hessian Minister for Economics and Technology at Frankfurt Airport", Herr Held, and funded by the "Flughafen Frankfurt Main AG".

2. Test aircraft

Two different types of aircraft were selected, the Fairchild Metro III (Fig. 1) and the Fokker 50 (Fig. 2). Both aircraft are powered by two turboprops each, the Metro III representing a smaller but somewhat noisier aircraft compared to the larger Fokker 50. Some overall design parameters are listed in Table I:

TABLE I: Test aircraft parameters

	Metro III SA 227	Fokker 50
Wing span (m)	17.37	29.00
Max. T.O. Mass (kg)	6577	18990
Typical Cruising Speed (kts|km/h)	248|459	282|522
Power Plant:	Garret TPE 331-11U-612G	Pratt & Whitney PW 125 B
Number of Engines	2	2
Engine Power (kW)	745.5	1864.0
Propeller:	Dowty Rotol	Dowty Rotol
Number of Blades	4	6
Diameter (m)	2.69	3.66

3. Test matrix and measurement site

Acoustic data were taken for three level flyover heights, i.e. 17000 ft (5182 m), 19000 ft (5791 m) and 21000 ft (6401 m) in respectively two opposite flight directions with the engines operating at cruise-power setting. Since relatively low flyover noise levels were expected the measurements were taken at night (between 0.00 am and 3.00 am) in a flat agricultural area located south of Frankfurt airport. This site was selected to benefit from existing navigational aids installed near airports and to thus realize a precise and reproducible flight path over the measurement station.

4. Environmental and operational data acquisition

In order to correctly evaluate acoustic test results, the local meteorological conditions and pertinent aircraft operational data were recorded.

4.1 Meteorological data

Simultaneously with the acoustic flyover measurements, a weather-balloon was raised by the "Deutscher Wetterdienst" near the test site to obtain profiles of atmospheric pressure, temperature, humidity and wind conditions versus height. Respective data records are presented in Figs. 3 and 4 up to a height of 2000 m. A complete data listing of wind conditions up to 6672 m and of temperature and humidity up to 4245 m are presented in Appendix I.

4.2 Aircraft operational data

No external devices were used to determine the aircraft operational data, but the pilots were instructed to read and record flight-height and -speed as well as air-temperature and power-

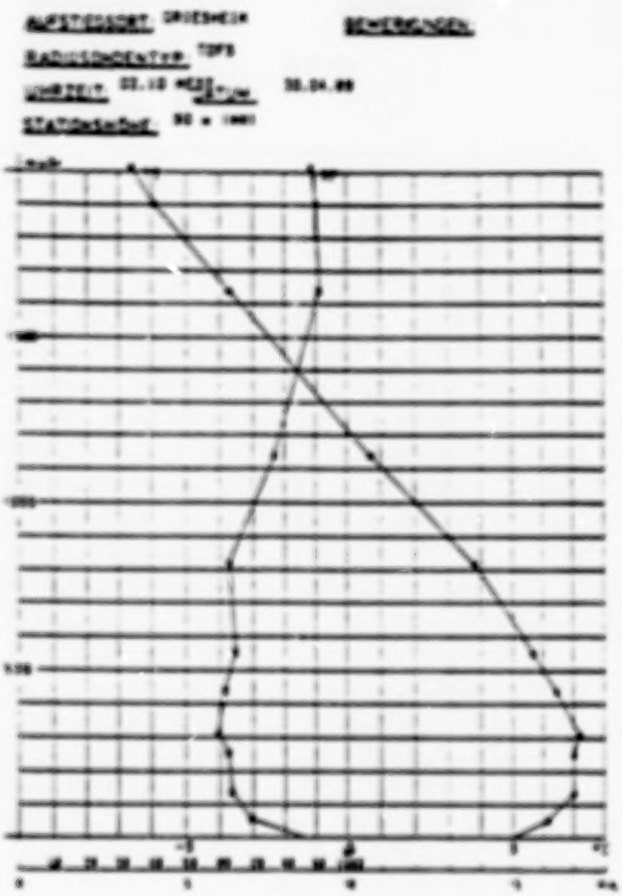


Fig. 3 Air-temperature (TT) and Relative Humidity (RF) versus height (in meters) above ground

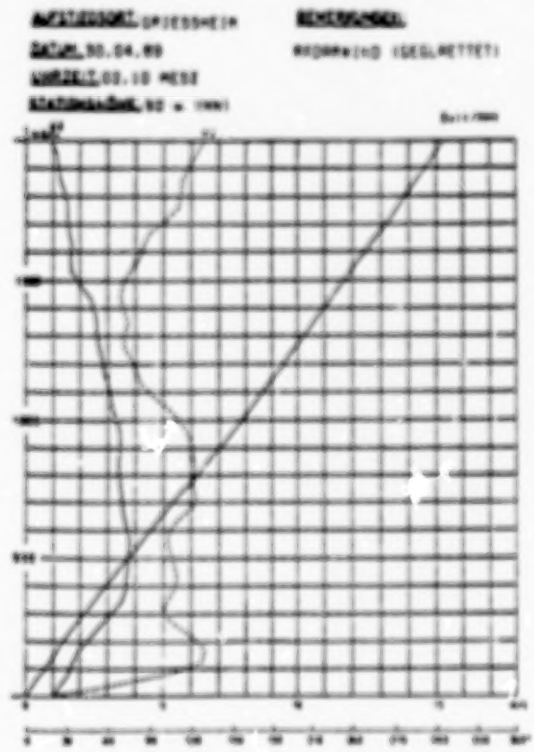


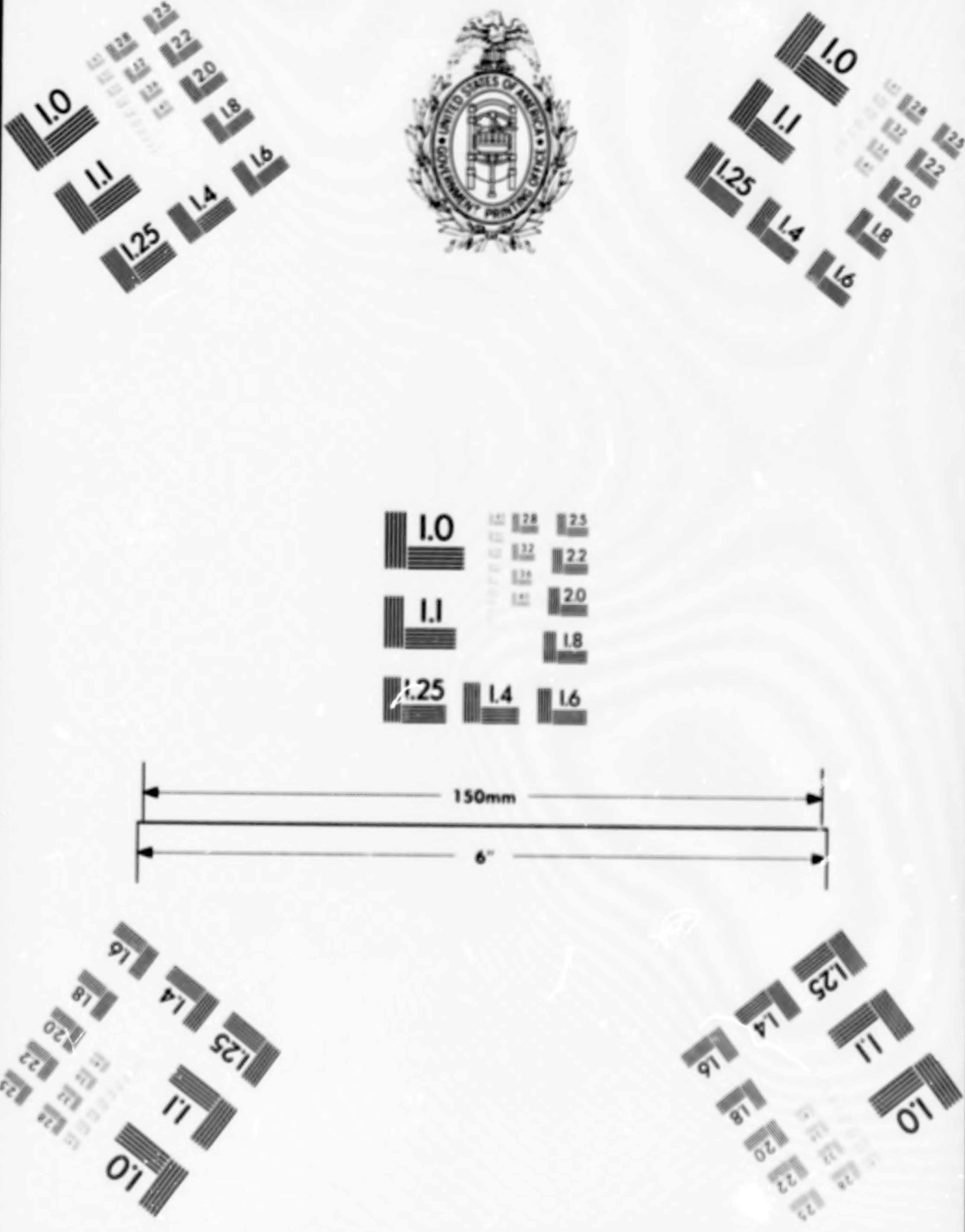
Fig. 4 Wind-direction (DD) and -magnitude (FF) versus height (in meters) above ground

Inflight - Info - Sheet

Type of aircraft: METRO III SA 227
Registration : D-CFEP
Type of engine : TPE 331

	T.O.W. : 5400 kg ATD : 2200 Z Pos. 7DME RID R 359 2201.. Z .8000.. Alt.		
1	4DME south of RID FL 170 northbound on R 359/179 RID	2212 Z	IAS/TAS 195 / 230 kts Temp.: -14 Clouds: CLEAR Power: 600 EGT 97% anti ice: ~~on~~ off
1	13DME north of RID FL 170 southbound on R 359/179 RID	2221 Z	IAS/TAS 195 / 21 kts Temp.: - 14 Clouds: CLEAR Power: 600 EGT 97% anti ice: ~~on~~ off
2	4DME south of RID FL 190 northbound on R 359/179 RID	2229 Z	IAS/TAS 190 / 230 kts Temp.: -20 Clouds: CLEAR Power: 600 97% anti ice: ~~on~~ off
2	13DME north of RID FL 190 southbound on R 359/179 RID	2237 Z	IAS/TAS 190 / 230 kts Temp.: -20 Clouds: CLEAR Power: 600 EGT anti ice: ~~on~~ off
3	4DME south of RID FL 210 northbound on R 359/179 RID	2244 Z	IAS/TAS 180 / 232 kts Temp.: -26 Clouds: CLEAR Power: 600 EGT 97% anti ice: ~~on~~ off
3	13DME north of RID FL 210 southbound on R 359/179 RID	2251 Z	IAS/TAS 180 / 232 kts Tem.: -26 Clouds: CLEAR Power: 600 EGT 97% anti ice: ~~on~~ off
	Pos. 4DME south of RID. FL 210 End of testflight request clearance to Frankfurt	2256	Z

Fig. 5 Data sheet as filled out by the Test-pilot of the Metro III aircraft


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
150mm
6"

Inflight - Info - Sheet

Type of aircraft: Fokker 50
Registration : D-AFKG
Type of engine : PW 125
29/30 APRIL 1989

	T.O.W. : 15 766 kg ATD : 2300 z Pos. 7DME RID R 359 ... 2304 z ... 7.100 ft Alt.	
1	4DME south of RID FL 170 northbound on R 359/179 RID 2310 z	IAS/TAS 211 kts / 274 kts Temp.: -15° Clouds: cavok Power: 80% TRQ cruise anti ice: ~~on~~ off
	13DME north of RID FL 170 southbound on R 359/179 RID 2317 z	IAS/TAS 218 kts / 283 kts Temp.: - 14° Clouds: cavok Power: 80% TRQ cruise anti ice: ~~on~~ off
2	4DME south of RID FL 190 northbound on R 359/179 RID 2324 z	IAS/TAS 209 kts / 281 kts Temp.: -20° Clouds: cavok Power: 78% TRQ cruise anti ice: ~~on~~ off
	13DME north of RID FL 190 southbound on R 359/179 RID 2331 z	IAS/TAS 212 kts / 286 kts Temp.: - 19° Clouds: cavok Power: 79% TRQ cruise anti ice: ~~on~~ off
3	4DME south of RID FL 210 northbound on R 359/179 RID 2338 z	IAS/TAS 201 kts / 278 kts Temp.: -24° Clouds: cavok Power: 73% TRQ cruise anti ice: ~~on~~ off
	13DME north of RID FL 210 southbound on R 359/179 RID 2345 z	IAS/TAS 203 kts / 282 kts Tem.: -24° Clouds: cavok Power: 74% TRQ cruise anti ice: ~~on~~ off
	Pos. 4DME south of RID, FL 210 End of testflight request clearance to Frankfurt	End of test in the air 2352 " " " on ground 0012 z

Fig. 6 Data sheet as filled out by the Test-pilot of the Fokker 50 aircraft

setting from the cockpit instrumentation during each flyover. "Inflight-Info-Sheets" are presented as Figs. 5 and 6.

Both aircraft are equipped with constant-speed propellers. Hence power is adjusted automatically by blade-pitch setting to maintain a constant rotational speed corresponding to the following values:

	Metro III	Fokker 50
Propeller rotational speed (rpm)	1543.	1025.

5. Acoustic data acquisition

Two Brüel & Kjaer 1/2"-Condenser Microphones (Type 4145) were positioned (in close proximity) underneath the flight path. The microphone signals were stored on an analog tape recorder. While one of the microphones was mounted on a 1.2 m pole, according to established noise certification regulations, the other microphone was installed close (and inverted) to a 0.4 m diameter ground board. This latter arrangement is frequently employed in scientific measurements since it represents the best device (other than a flush mounted microphone in a large concrete surface) to avoid ground reflection interferences. Such ground reflections tend to heavily distort source noise spectra, depending on the particular relation between microphone height and the fundamental frequency wavelength of the signature to be measured.

Examples of such microphone arrangements are presented in Fig. 7. However, for the tests described herein, the microphones were located on a hard and flat "earthy" surface.

From basic priciples it is known that pressure doubling occurs at an acoustically hard surface. Levels obtained by ground based microphone arrangements are higher by up to 8 dB(!) compared to those from pole-microphone installations. If however the microphone height selected (accidentally) corresponds to multiples of

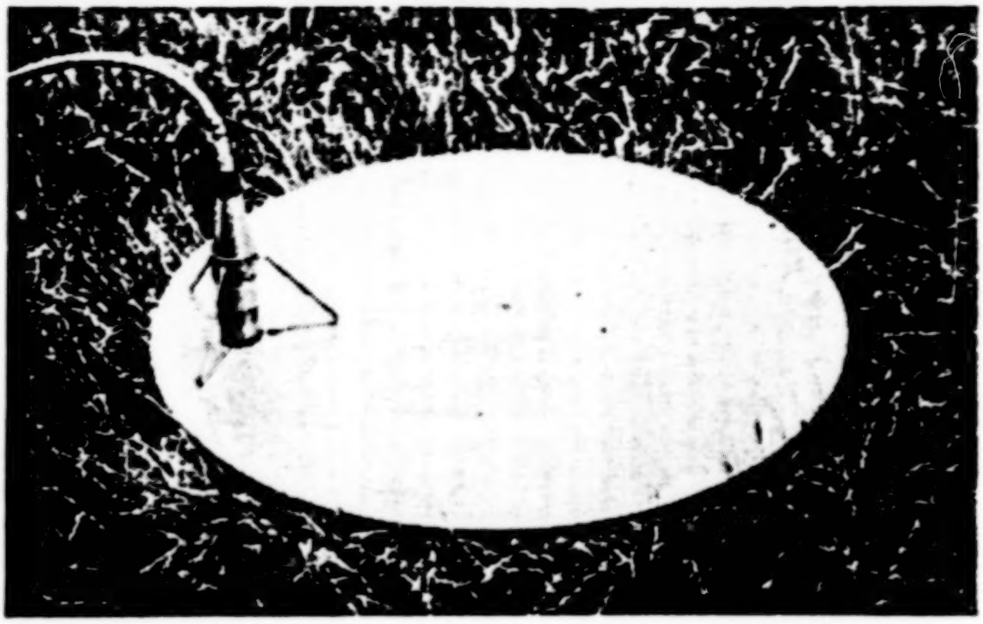


Fig. 7 Illustrations of ground-board (top) and 1.2 m pole microphone (bottom) arrangements

Original figures not available.

the sound signature's wavelength both microphone arrangements may give identical results.

A detailed discussion of ground reflection effects on propeller aircraft flyover noise measurements is provided in [1].

6. Acoustic test results

Noise data will be presented as measured in terms of overall levels, level time-histories, and narrowband spectra. Since no acoustical significant variations in flyover height could be tested and acoustic signatures turned out to be dominated by the low-frequency (about 100 Hz) fundamental of propeller rotational noise, no correction is applied to the data with respect to flight height, air-temperature, atmospheric attenuation, etc.

Such corrections indeed should not be applied in an overall manner, since the magnitude of respective level differences would equal the observed data scatter caused by stochastic atmospheric disturbances. Application of such corrections should therefore be left to specialists who are then to apply sophisticated computer codes for the calculation of the transmission attenuation based on detailed meteorological data.

6.1 Maximum linear- and A-weighted overall sound pressure levels

Tables II and III contain maximum linear (analyzed with time constant "fast") and A-weighted (analyzed with time constant "slow") overall levels numbered in the order of test flights except the first flight of the Fokker 50 aircraft at 17000 ft height which had been missed due to communication problems. The first measurement in that listing (Table II) does not pertain to the en route noise test series, but represents the climb-out signature of the test aircraft Metro III and has only been listed for completeness.

Table II

En-Route Noise Measurement (Frankfurt/Griesheim; 30.4.89)

Aircraft Type: Metro III SA 227
Propeller Diameter = 2.692 m (4 Blades)

Operational Conditions: TAS = 230.0 kts
Propeller Rot. Speed = 1543.3 rpm (BPF = 102.9 Hz)

No.	Flight Height ft	Air Temp. °C	M_{Hel}	$L_{A,max}$ (Slow) dB(A)		L_{max} (Fast) dB	
				Ground Mic	1.2 m Mic	Ground Mic	1.2 m Mic
1*	8000	-	-	61.7	56.9	78.4	74.2
2	17000	-14	0.7675	52.9	48.9	70.3	67.2
3	17000	-14	0.7675	54.1	50.5	72.0	68.5
4	19000	-20	0.7764	50.6	47.5	68.0	65.7
5	19000	-20	0.7764	50.2	47.5	68.1	65.9
6	21000	-26	0.7858	52.1	48.2	68.7	65.9
7	21000	-26	0.7858	49.9	46.0	68.0	64.9
Level Averages (without No. 1)				51.6	48.1	69.2	66.4
Level Differences (Ground -1.2 m)				Δ = 3.5		Δ = 2.8	
Background Noise Levels:				39.0	37.9	54.0	53.0

* Take-off Power Setting

Listing of measured maximum overall noise levels from Metro III aircraft fly-overs

Table III

En-Route Noise Measurement (Frankfurt/Griesheim; 30.4.89)

Aircraft Type: Fokker 50
Propeller Diameter = 3.66 m (6 Blades)

Operational Conditions: TAS (Average) = 280.5 kts
Propeller Rot. Speed = 1025.0 rpm (BPF = 102.5 Hz)

No.	Flight Height ft	Air Temp. °C	M_{Hel}	$L_{A,max}$ (Slow) dB(A)		L_{max} (Fast) dB	
				Ground Mic	1.2 m Mic	Ground Mic	1.2 m Mic
8	17000	-14	0.7554	51.0	48.5	67.5	64.4
9	19000	-20	0.7643	53.9	51.1	70.9	68.8
10	19000	-19	0.7628	46.9	43.5	63.7	----
11	21000	-24	0.7704	45.9	43.9	63.0	60.8
12	21000	-24	0.7704	46.6	44.0	63.7	60.1
Level Averages				48.9	46.2	65.8	63.5
Level Differences (Ground -1.2 m)				Δ = 2.7		Δ = 2.3	
Background Noise Levels:				39.0	37.9	54.0	53.0

Listing of measured maximum overall noise levels from Fokker 50 aircraft fly-overs

Together with the flyover noise levels these tables also contain the calculated values of respective helical propeller blade-tip Mach numbers, referenced to the air temperature at flight height.

Calculated level averages (as determined from flyovers at different heights!) may be taken to correspond to the average flight height of 19000 ft. From the measured and listed background noise levels, on average a sufficiently large signal-to-noise ratio of almost 10 dB is observed.

Levels on the ground turn out to be higher by some 3 dB compared to those from the 1.2 m pole microphone. This level difference can be taken as an order-of-magnitude value which may be considered as typical for conventional propeller-driven aircraft. Not to hamper further data interpretation by accounting for ground reflection effects, only ground microphone obtained noise signatures will be discussed.

In Figs. 8 and 9 overall linear and A-weighted noise levels are plotted versus flyover height for both aircraft. As a simple reference, the level attenuation for spherical spreading ($1/r^2$-law) is indicated. Except for one data point (No. 9/Fokker 50) noise levels are quite close to this reference. As will be shown later there is no explanation for the noise level of flyover No. 9 to be almost 7 dB higher than expected. Effects of stochastic atmospheric disturbances may have caused this discrepancy.

From an inspection and comparison of the data as presented in Figs. 8 and 9 the Metro III aircraft seems 2.5 dB noisier compared to the Fokker 50 aircraft. From the experience gained within extensive wind tunnel propeller noise tests [2] such a result may be assumed to originate from a slightly higher helical blade-tip Mach number as observed for the Metro III compared to that of the Fokker 50.

For both aircraft the differences between linear and A-weighted noise levels range from 17 dB to 18 dB. This difference roughly

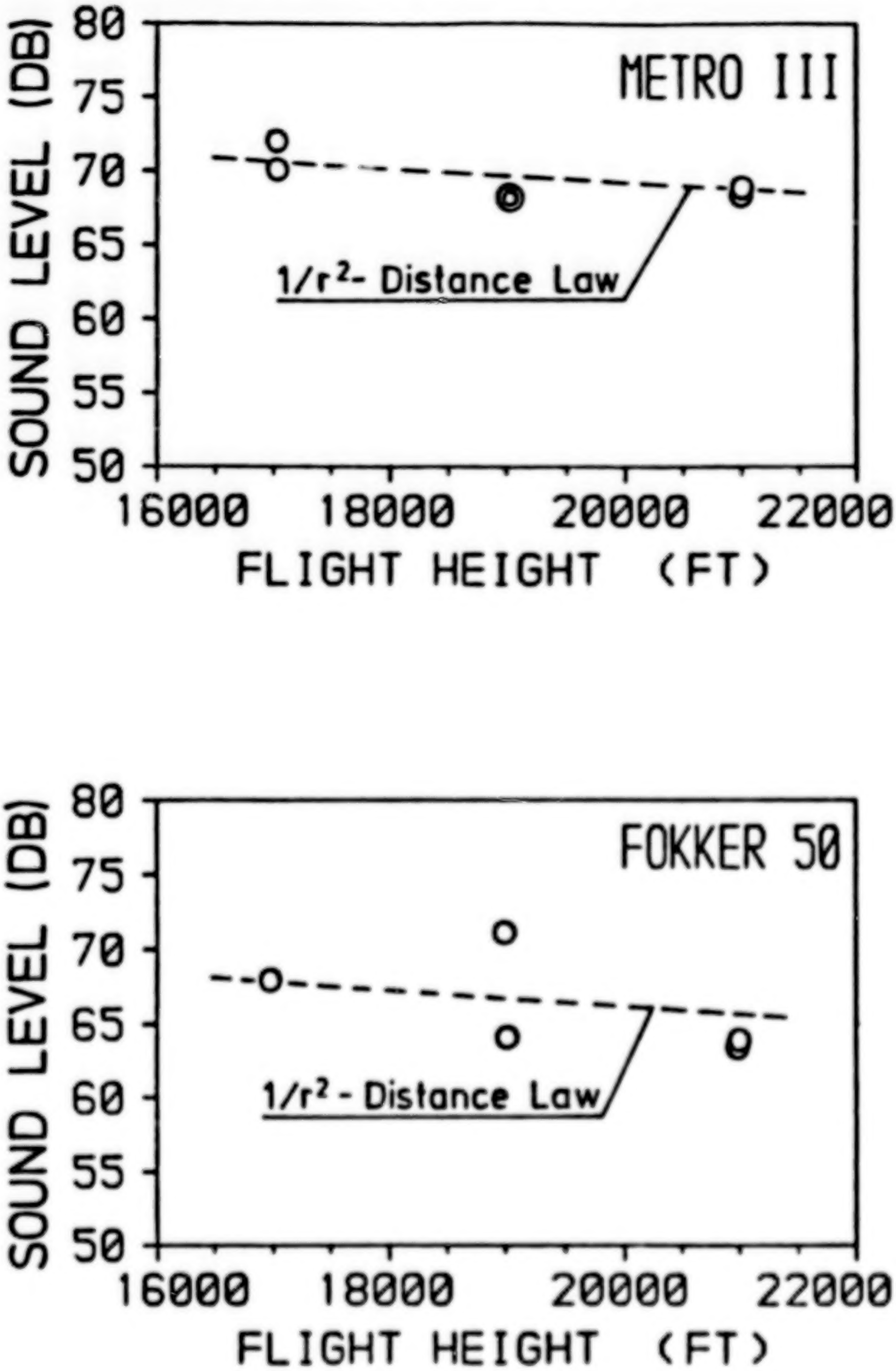
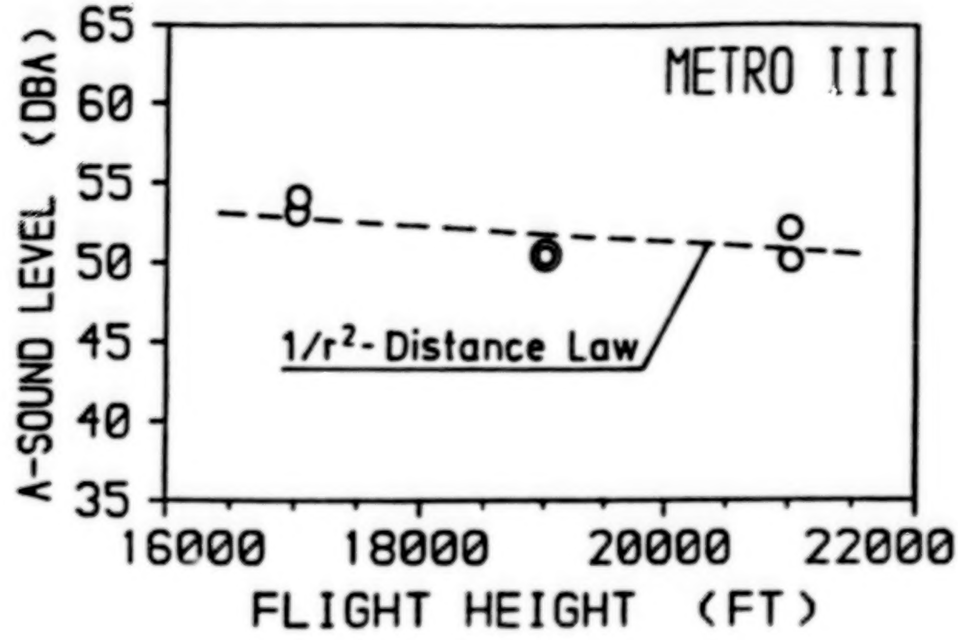


Fig. 8 As measured maximum overall flyover noise levels versus flight height



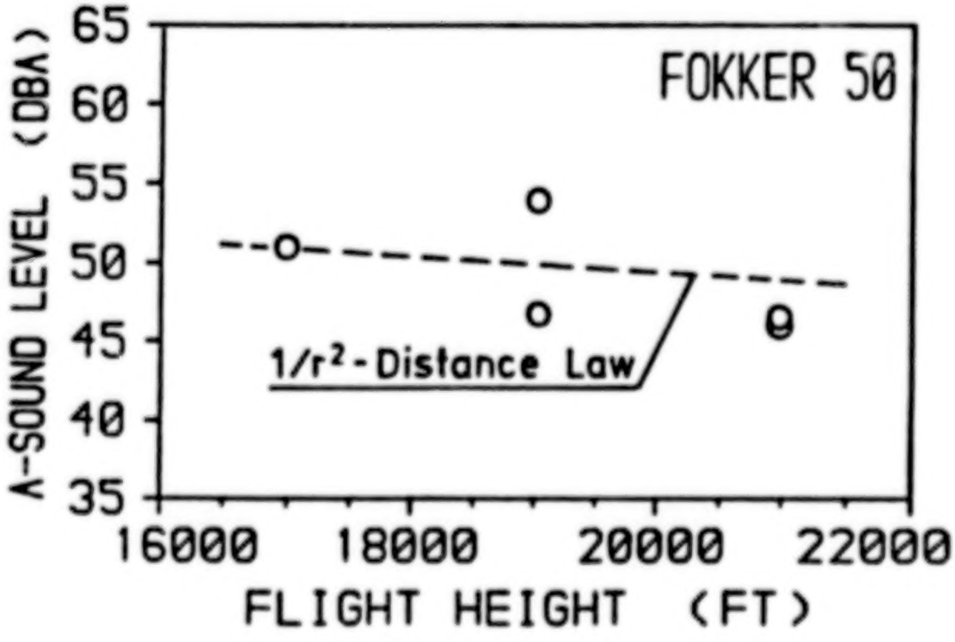


Fig. 9 As measured maximum A-weighted overall fly-over noise levels versus flight height

corresponds to the A-weighting attenuation at a frequency of 100 Hz to 125 Hz which happens to coincide with the respective blade passing frequencies of both aircraft. Already at this stage of data analysis, one may safely conclude that flyover noise signatures are entirely governed by the blade passing frequencies.

6.2 Sound level time-histories

In order to select appropriate instances in flyover time for later spectral analysis it is necessary to initially plot overall level time histories. Such information is presented in Appendix II both in terms of linear (time constant "fast") and A-weighted (time constant "slow") overall level time-histories.

Typically all of these histories exhibit level fluctuations which range up to 15 dB (!) for the representations of overall linear levels. Two explanations may be offered: There are either atmospheric effects during sound transmission over long distances, or sound beats due to the superposition of sound signatures originating from two noise sources (propellers) radiating at slightly different frequencies (rotational speeds).

To definitely prove that in fact sound beats are the reason for these (periodic) level fluctuations, some more analysis is necessary: If two pure-tone noise sources with identical pressure amplitudes p_o are considered, one operating at a circular frequency of ω_1 and the other at ω_2 , the time history of the combined pressure amplitude may be written as follows:

(1) $$p = 2\, p_o \cdot \cos\left[(\Delta\omega/2)\cdot t \right] \cdot \cos(\omega_1 \cdot t)$$

(with $\Delta\omega = \omega_1 - \omega_2$).

From this equation it is obvious that the pressure amplitude may be doubled ($\hat{=}$ +6 dB) or tends to zero ($\hat{=}$ minus ∞ dB) as a periodic function of time corresponding to the cosine of the beat frequency which is defined as

(2) $\omega_s = \Delta\omega/2 = 2\pi/t_s$.

Now the effect of such beats on different source frequencies may be determined as a function of propeller rotational speed from the relation

(3) $\omega = 2\pi f_{Harm.} = 2\pi (N/60)\cdot BLN\cdot HN$

and thus

(4) $\Delta\omega = 2\pi (\Delta N/60)\cdot BLN\cdot HN$.

From eqs. (2), (3) and (4) the time period of pressure fluctuations may be calculated as

(5) $t_S = 2\pi/(\Delta\omega/2) = 2/[(\Delta N/60)\cdot BLN\cdot HN]$

exhibiting faster repetitions in time of pressure minima and maxima with increasing source frequency, i.e. for higher harmonic numbers HN. It is this particular feature of pressure level fluctuations which allows the distinction between the stochastic effects of long range sound transmission through a turbulent atmosphere and the periodic effects of noise beats.

In order to demonstrate that effect from the measured data, it is necessary to compare time histories of different rotational harmonic levels. Such analysis, however, is somewhat difficult because of the Doppler-shift in frequency with flyover time. As will be shown later, tracking filter techniques could not be applied since - as a result of beats and the marginal signal-to-noise ratio - harmonic levels frequently submerge into the background noise floor. Therefore flyover signatures were analysed in terms of adjacent 1/3-octave band level histories with the fundamental frequency moving (continuously) from the 125 Hz band (aircraft in approach) into the 100 Hz band and finally into the 80 Hz band for the aircraft receeding from the measuring station. When combining such plots (synchronized in time) one may obtain continuous level time traces at least for the first two

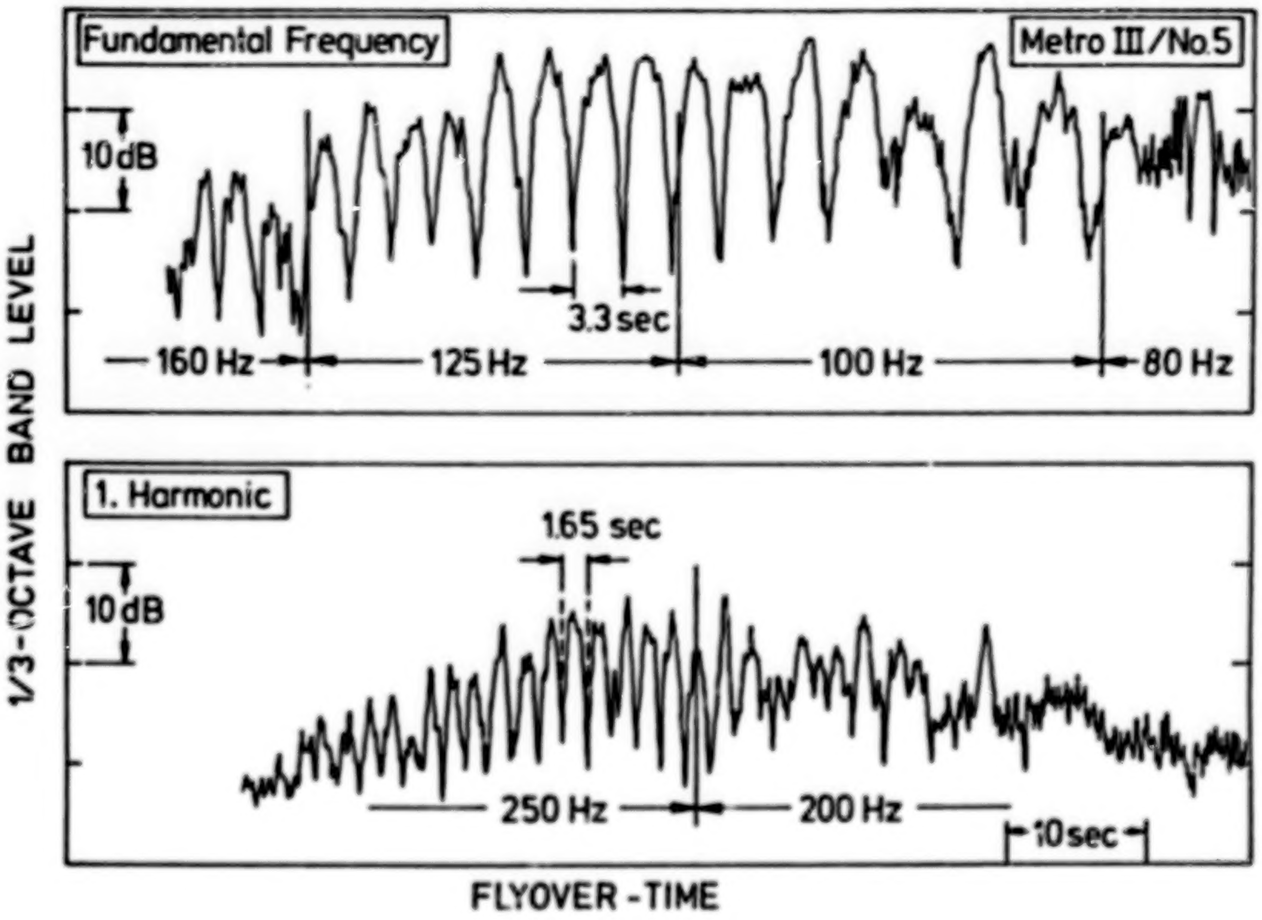


Fig. 10 1/3-octave band level time-histories of Metro III flyover No. 5

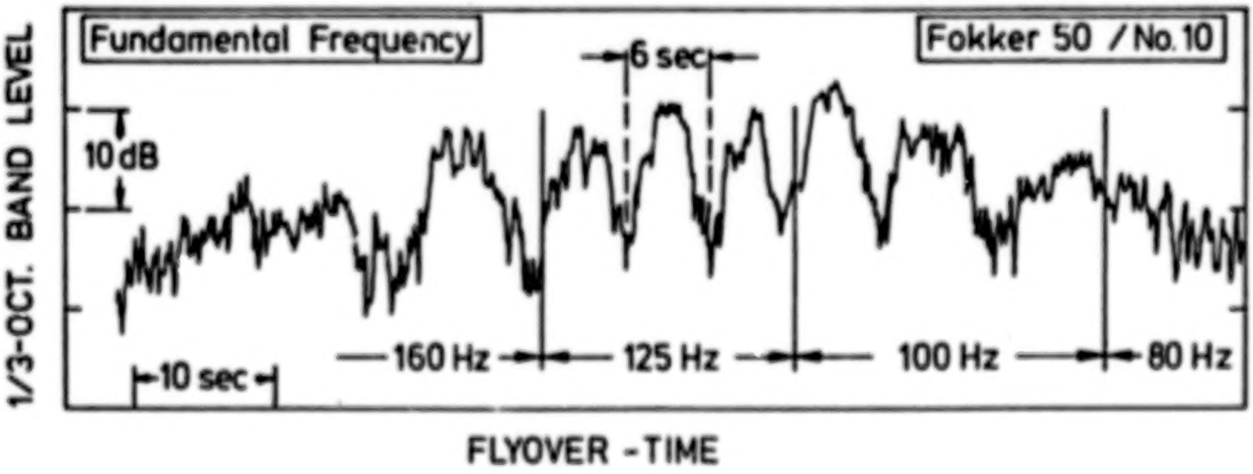


Fig. 11 1/3-octave band level time-history of Fokker 50 flyover No. 10

rotational frequencies, which are apart by about 100 Hz and thus never contribute to the same 1/3-octave band level.

An example of such an analysis is presented in Fig. 10 for both the fundamental frequency of the Metro III flyover noise signature and for the first harmonic level. From a comparison of level fluctuations in time for both frequencies, the first harmonic ($f \sim 200$ Hz) exhibits twice the beat frequency value (i.e. half the corresponding time period) as is observed for the fundamental frequency, thus proving that level fluctuations are a result of beats due to slightly different rotational speeds of both propellers. From this example a difference in rotational speed of 9 rpm can be calculated from eq. (5), to be responsible for these rather significant level fluctuations.

Similar effects can be observed from the Fokker 50 flyovers. An example is given in Fig. 11 for the fundamental frequency only, because no harmonic emerges from the background noise floor. In this case a difference in rotational speed between both propellers of 3 rpm is determined.

6.3 Narrowband spectra

As is obvious from the level time-traces presented in the preceding paragraph, the results of narrowband spectral analysis will heavily depend on the instant in flyover time selected. To first demonstrate the variety of spectral characteristics occurring during one flyover event, to further determine the relevant (Doppler-shifted) values of the fundamental frequency and to thus attempt a correlation of the flyover signatures with noise emission time (radiation angle), narrowband spectra (bandwidth Δf = 3.125 Hz) were obtained at numerous instances in time for each of the flyovers of the Metro III and the Fokker 50.

For this purpose it was felt to be sufficiently accurate to obtain single sample spectra, manually released and correlated with flyover time by eye-tracing of a simultaneously created

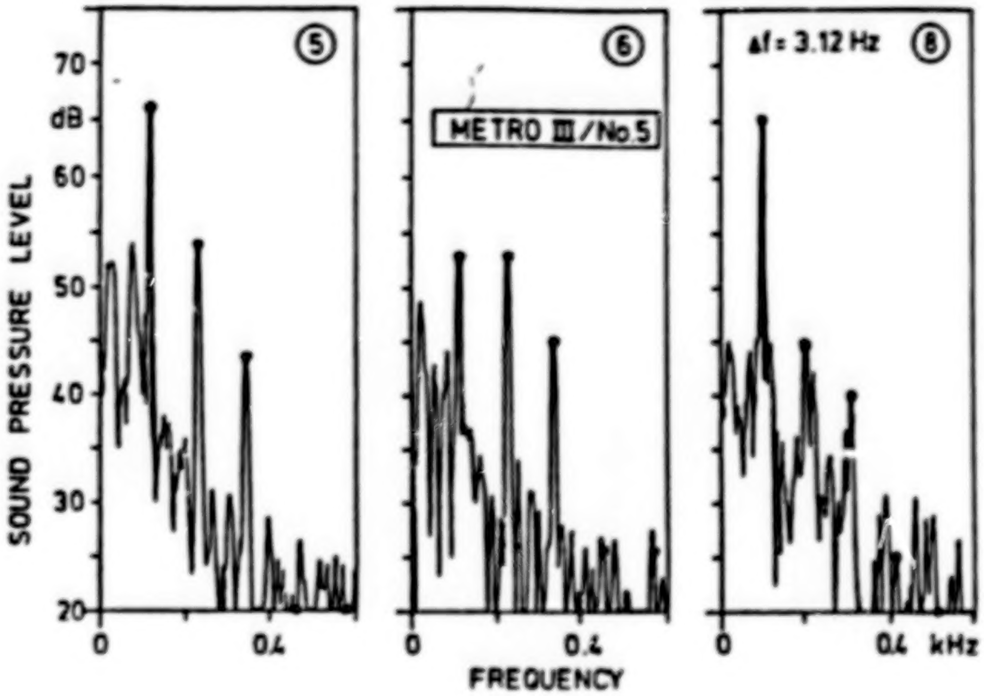


Fig. 12 Narrowband frequency spectra at different instances in time for Metro III flyover No. 5

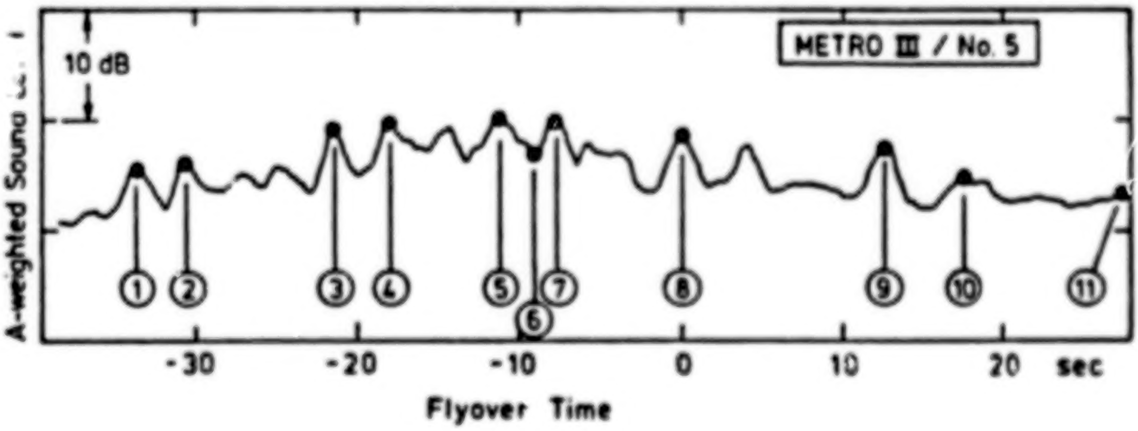


Fig. 13 Overall A-sound level time history of Metro III flyover No. 5 indicating 11 instances in time where narrowband spectral analysis was performed

plot of the respective overall level time history. Fig. 12 presents examples of narrowband spectra as obtained in the course of that procedure for the Metro III flyover No. 5, indicating a seemingly chaotic variation of propeller harmonic levels for different instances in time. Respective times - corresponding to all samples taken - are indicated in the overall level trace as presented in Fig. 13 (in the spectra of Fig. 12 reference is made to corresponding sample numbers of Fig. 13).

From every spectrum the instantaneous value of the fundamental frequency is obtained. Its variation with time can therefore be checked against the calculated Doppler-shift in frequency. From basic principles, a frequency shift with flyover time is due to the relative motion of a source with respect to the observer and is determined according to

(6) $$f(t) = f_o/(1-M\cos\Theta)$$

with the elevation angle

(7) $$\Theta = 180\ \mathrm{deg} - \mathrm{arcctg}\ (v \cdot t/H).$$

In eq. (7) "negative times" pertain to noise radiated from the aircraft in approach, time t is zero for noise radiated from overhead and "positive times" pertains to noise radiated during departure.

Since the value of the Mach number M in eq. (6) is determined from the relative speed of the aircraft with respect to the measuring microphone, the effects of wind speed and -direction at the flight height must be accounted for. From the meteorological data-records the wind direction can be determined as near zero degrees (i.e. from north) and its average magnitude to be approximately 4 m/s. Since flight No. 5 was conducted from north to south, the aircraft's speed over ground is obtained by summing up both IAS (see Fig. 3) and wind speed to end up with a value of 122.3 m/s. To finally determine the corresponding Mach number the speed of sound needs to be approximated. In order to reduce

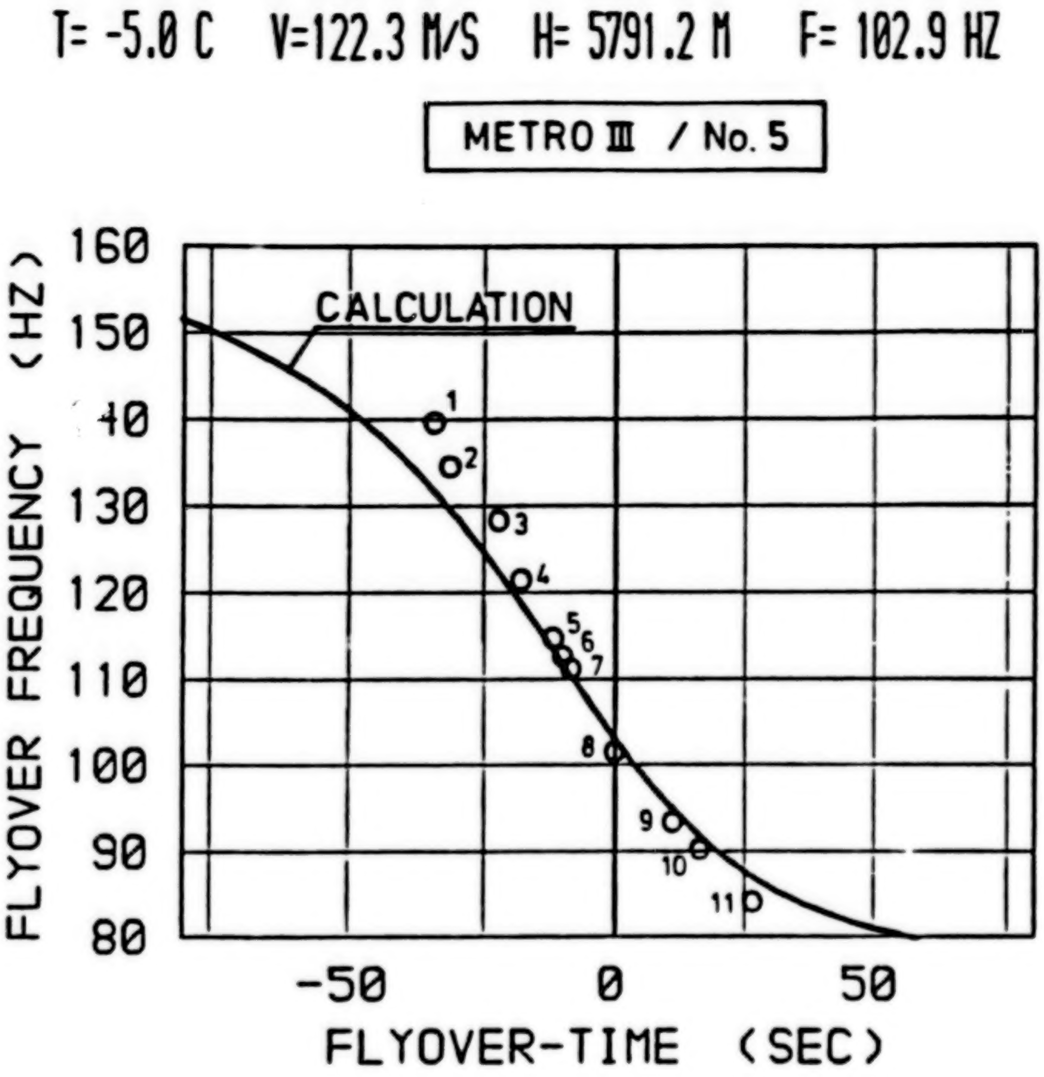


Fig. 14 Comparison of measured and calculated Doppler-shift in blade passing frequency versus time for the Metro III flyover No. 5

calculation efforts for the purpose of this rather qualitative analysis an average speed of sound was determined to correspond to an average (from ground level to flight height) air-temperature of -5°C.

Following this argumentation and using eqs. (6) and (7), the calculated frequency variation is plotted in Fig. 14 versus noise emission time. The correlation of that time-scale with measured level time histories can now be obtained by time-shifting the measured data points (frequency values) to yield a best fit between calculated and measured curves. From this procedure (which however assumes flight- and propeller rotational speed to be correctly measured) the absolute time scale had been determined as indicated on the abszissa of Fig. 13. That figure now indicates that maximum noise levels are emitted for the aircraft in approach.

The same type of analysis was conducted for the Fokker 50 flyover No. 10 (again with direction from North to South) yielding similar results, as presented in Figs. 15 and 16.

Finally some narrowband analyses were performed to check on the reason of the overall level difference of about 7 dB for the two Fokker 50 flyovers at 19000 ft height (No. 9 and No. 10). Fig. 17 presents spectra which pertain to approximately corresponding maxima and minima of level time-traces from flyovers No. 9 and No. 10. The observed difference in overall levels is dominated by level differences at the fundamental frequency. Since no contribution of extraneous noise sources can be detected from the spectra, no explanation other than strong atmospheric effects on noise transmission can be offered as a reason for this significant level difference.

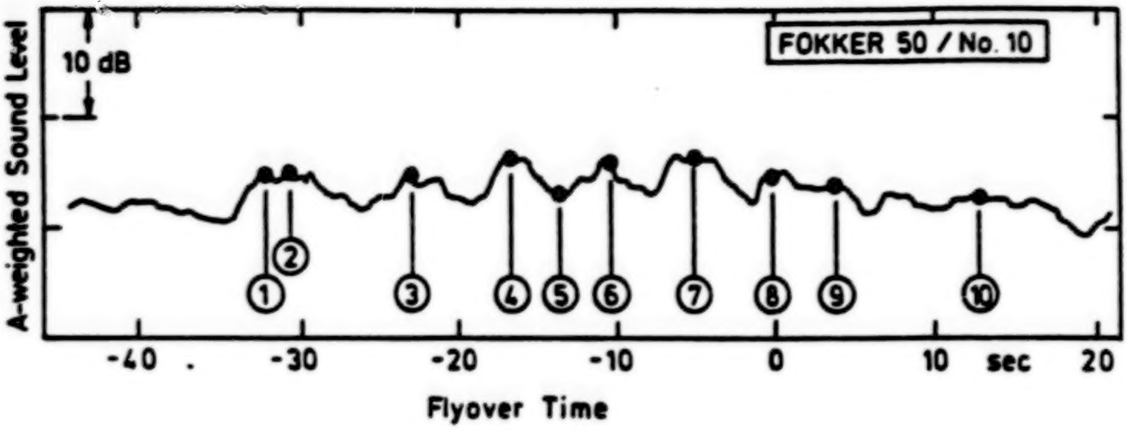


Fig. 15 Overall A-sound level time history of Fokker 50 flyover No. 10 indicating 10 instances in time where narrowband spectral analysis was performed

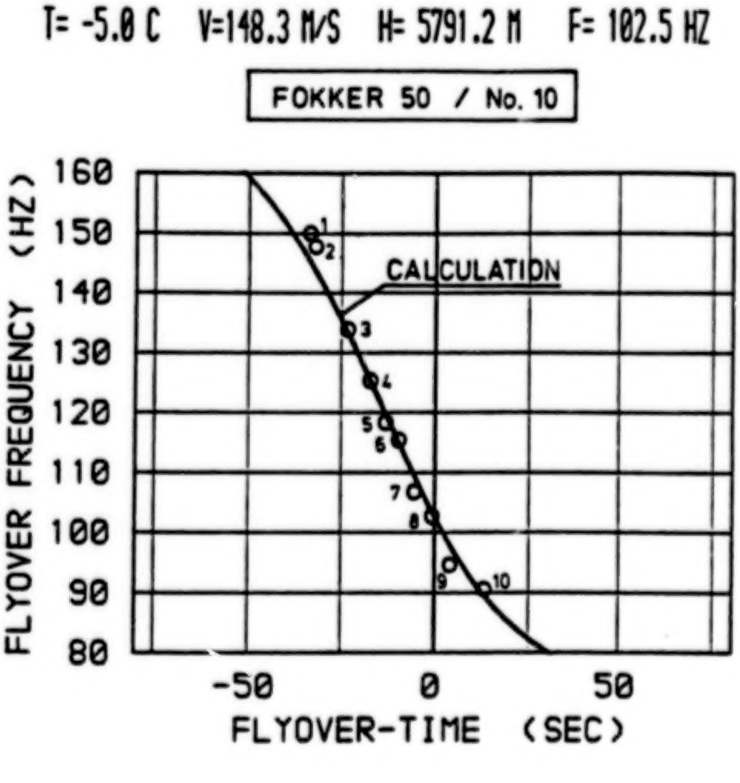


Fig. 16 Comparison of measured and calculated Doppler-shift in blade-passing frequency versus time for the Fokker 50 flyover No. 10

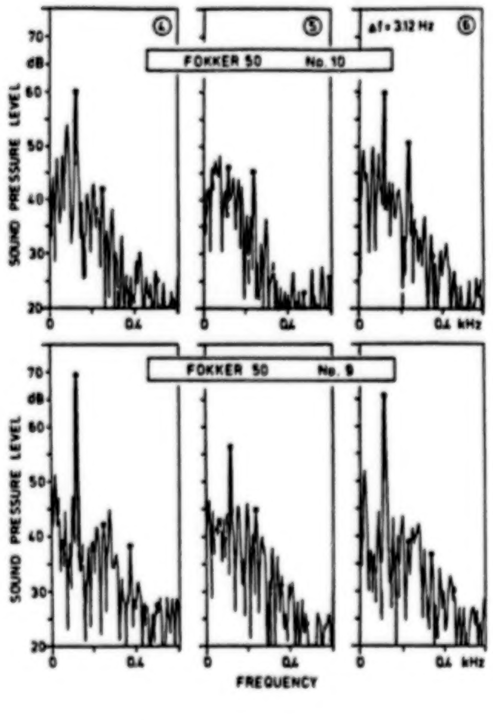


Fig. 17 Comparison of narrowband spectra at different instances in time for Fokker 50 flyover No. 10 (upper row) with spectra taken at corresponding times but for flyover No. 9 (lower row) at the identical flyover height

7. Conclusions

Since this report is thought as an initial contribution to a reference data base which will allow judgment of the extent of annoyance caused by propfan powered aircraft, no final conclusions should yet be drawn from the results. However, two observations should be emphasized which are thought as typical for propeller powered aircraft noise immission:

- First, the propeller rotational noise fundamental (at a frequency of about 102 Hz) dominates the overall en-route noise level and thus yields an "attenuation" of almost 18 dB due to the A-weighting. This might be considered a problem since the A-weighting function is suspected to not correctly simulate the human noise perception at low frequencies.

- Second, noise beats were found to cause periodic A-sound level fluctuations in the order of 5 dB, due to inadequate or altogether missing synchronization of propeller rotational speeds. Such effects are felt to represent an additional annoyance factor and efforts should therefore be undertaken to solve this problem for future propfan powered aircraft.

8. Summary

Increasing complaints about aircraft en route noise shows the necessity to judge en route noise characteristics of advanced propfan powered aircraft. Such new type aircraft are expected to be in service within the next few years. For this purpose an extensive data base on en route noise levels of conventional turboprop aircraft is needed. Respective measurements have been undertaken on two twin-engine turboprop aircraft at different flight heights. Noise data are presented together with operational parameters and meteorological data. No noise level correction has been performed with respect to environmental parameters influencing noise generation and transmission through the atmosphere. Data analysis is performed in terms of overall linear and

A-weighted noise level time histories. Corresponding level maxima are listed for two microphone arrangements, i.e. using a ground board and a 1.2 m pole. Examples of narrowband spectral analyses are presented to demonstrate the characteristic features of noise signatures, namely the dominance of the low frequency propeller rotational noise fundamental and the occurrence of noise beats due to different rotational speeds of the two propellers. This latter effect causes periodic A-sound level fluctuations of up to 5 dB.

9. Acknowledgment

The measurement campaign was initiated by Herr Held, Noise Abatement Commissioner of the Hessian Minister for Economics and Technology at Frankfurt Airport , and funded by the Flughafen Frankfurt Main AG . Herr Held perfectly organized the cooperation between the Hessisches Landesamt für Umwelt , Deutscher Wetterdienst and the aircraft flight crews. The permission given to DLR to take noise data at the same time is highly appreciated.

10. References

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[2] Dobrzynski, W.
Heller, H.
Powers, J.
Densmore, J.
DFVLR/FAA Propeller Noise Tests in the German-Dutch Wind Tunnel DNW.
(6 Appendices)
DFVLR-IB 129-86/3, 1986
FAA Report No. AEE 86-3, 1986.

A P P E N D I X   I

Detailed listing of

meteorological data versus height

Griessheim 30.04.89 02.10 mesz Nr.

Richtung u. Geschw.geglaettet

Punkt	Zeit	DDD/Gr.	FF/m/s	Hoehe-rel	Hoehe-abs
0	0.00	20	1.0	0	0
1	0.20	23	2.7	27	54
2	0.40	31	5.0	75	96
3	1.00	34	6.4	119	143
4	1.20	40	6.5	170	198
5	1.40	49	6.0	219	241
6	2.00	56	5.4	261	282
7	2.20	63	5.0	302	322
8	2.40	76	5.1	344	366
9	3.00	73	5.4	386	407
10	3.20	74	5.5	428	450
11	4.00	75	5.3	490	531
12	4.20	76	5.2	552	573
13	4.40	74	5.2	594	616
14	5.00	72	5.6	637	659
15	5.20	70	6.1	680	701
16	5.40	70	6.2	722	744
17	6.00	69	6.0	761	779
18	6.20	68	6.1	800	821
19	6.40	68	6.1	843	866
20	7.00	69	6.0	884	902
21	7.20	69	6.0	923	945
22	7.40	68	5.8	965	986
23	8.00	66	5.5	1008	1030
24	8.20	63	5.1	1051	1073
25	8.40	62	4.6	1094	1115
26	9.00	60	4.2	1136	1158
27	9.20	57	4.0	1177	1197
28	9.40	56	3.9	1221	1246
29	10.00	54	3.6	1266	1287
30	10.20	52	3.6	1308	1329
31	10.40	52	3.8	1352	1375
32	11.00	51	3.6	1396	1417
33	11.20	48	3.5	1441	1466
34	11.40	40	3.6	1488	1510
35	12.00	33	3.9	1535	1561
36	12.20	33	4.2	1582	1603
37	12.40	34	4.3	1627	1652
38	13.00	32	4.6	1671	1691
39	13.20	31	5.1	1714	1737
40	13.40	31	5.6	1762	1788
41	14.00	29	5.7	1811	1835
42	14.20	26	5.7	1857	1880
43	14.40	24	5.9	1904	1928
44	15.00	23	6.2	1952	1977
45	15.20	19	6.5	2002	2027
46	15.40	13	6.8	2049	2072
47	16.00	9	7.0	2096	2121
48	16.20	5	7.1	2145	2169
49	16.40	2	7.2	2193	2217
50	17.00	357	7.4	2242	2268
51	17.20	354	7.6	2291	2315
52	17.40	352	7.5	2342	2370
53	18.00	350	7.7	2394	2418
54	18.20	350	7.8	2442	2467
55	18.40	353	7.6	2490	2513
56	19.00	350	7.8	2538	2563
57	19.20	6	8.6	2586	2609

Punkt	Zeit	DDD/Gr.	FF/m/s	Hoehe-ml	Hoehe-abs
58	19.40	10	8.8	2627	2645
59	20.00	13	7.9	2665	2685
60	20.20	18	6.6	2706	2727
61	20.40	19	5.7	2745	2764
62	21.00	19	5.2	2784	2805
63	21.20	19	5.1	2825	2845
64	21.40	20	5.6	2865	2886
65	22.00	24	6.5	2910	2934
66	22.20	30	7.4	2958	2982
67	22.40	36	7.9	3004	3026
68	23.00	39	8.1	3051	3077
69	23.20	36	8.3	3099	3122
70	23.40	28	7.9	3147	3172
71	24.00	19	7.3	3197	3222
72	24.20	8	6.5	3247	3272
73	24.40	5	5.2	3294	3316
74	25.00	12	4.1	3340	3365
75	25.20	15	3.4	3386	3407
76	25.40	15	3.5	3432	3457
77	26.00	15	4.0	3482	3507
78	26.20	14	4.5	3527	3547
79	26.40	16	5.1	3571	3596
80	27.00	16	5.6	3619	3643
81	27.20	16	5.9	3664	3686
82	27.40	19	5.8	3707	3729
83	28.00	20	5.5	3753	3777
84	28.20	16	5.2	3801	3826
85	28.40	13	5.0	3848	3871
86	29.00	16	6.0	3895	3920
87	29.20	18	6.6	3960	4001
88	29.40	17	4.9	4019	4038
89	30.00	15	3.7	4072	4107
90	30.20	9	3.8	4133	4159
91	30.40	359	4.0	4183	4208
92	31.00	356	4.0	4230	4253
93	31.20	7	3.8	4278	4303
94	31.40	13	3.8	4327	4351
95	32.00	6	3.8	4373	4395
96	32.20	1	4.0	4417	4440
97	32.40	353	4.3	4467	4494
98	33.00	346	4.5	4514	4535
99	33.20	345	4.5	4557	4579
100	33.40	344	4.5	4602	4625
101	34.00	345	3.9	4648	4671
102	34.20	345	3.0	4692	4714
103	34.40	341	2.5	4742	4771
104	35.00	341	2.5	4790	4810
105	35.20	348	2.6	4829	4849
106	35.40	352	2.5	4871	4893
107	36.00	350	2.4	4922	4951
108	36.20	358	2.5	4973	4995
109	36.40	12	2.6	5019	5043
110	37.00	22	2.7	5065	5088
111	37.20	21	2.8	5114	5141
112	37.40	15	2.9	5160	5180
113	38.00	25	3.0	5203	5227
114	38.20	39	3.2	5249	5271
115	38.40	44	3.1	5298	5325
116	39.00	49	3.0	5350	5375
117	39.20	57	3.3	5400	5425
118	39.40	55	3.6	5452	5480
119	40.00	49	3.9	5506	5533
120	40.20	48	4.1	5556	5580

121	40.40	48	4.2	5603	5627
122	41.00	48	4.1	5650	5674
123	41.20	45	4.1	5701	5728
124	41.40	44	4.3	5753	5779
125	42.00	47	4.4	5805	5831
126	42.20	50	4.5	5849	5867
127	42.40	51	4.8	5898	5929
128	43.00	51	4.4	5950	5972
129	43.20	50	4.1	6001	6031
130	43.40	48	2.8	6058	6086
131	44.00	46	3.5	6105	6124
132	44.20	41	3.6	6148	6172
133	44.40	36	4.1	6193	6214
134	45.00	36	4.1	6240	6266
135	45.20	37	3.7	6288	6310
136	45.40	41	3.7	6332	6354
137	46.00	53	4.1	6384	6414
138	46.20	65	4.3	6434	6454
139	46.40	66	4.7	6478	6502
140	47.00	65	5.2	6529	6556
141	47.20	64	5.4	6579	6602
142	47.40	61	5.5	6627	6653
143	48.00	60	5.7	6672	6691

griessheim 30.04.89 02.10 mesz nr. 2

pkt-----ppp-----tt---tftf--rf-----td--tddiff---h.ue.gr--dt/100m--bemerk.

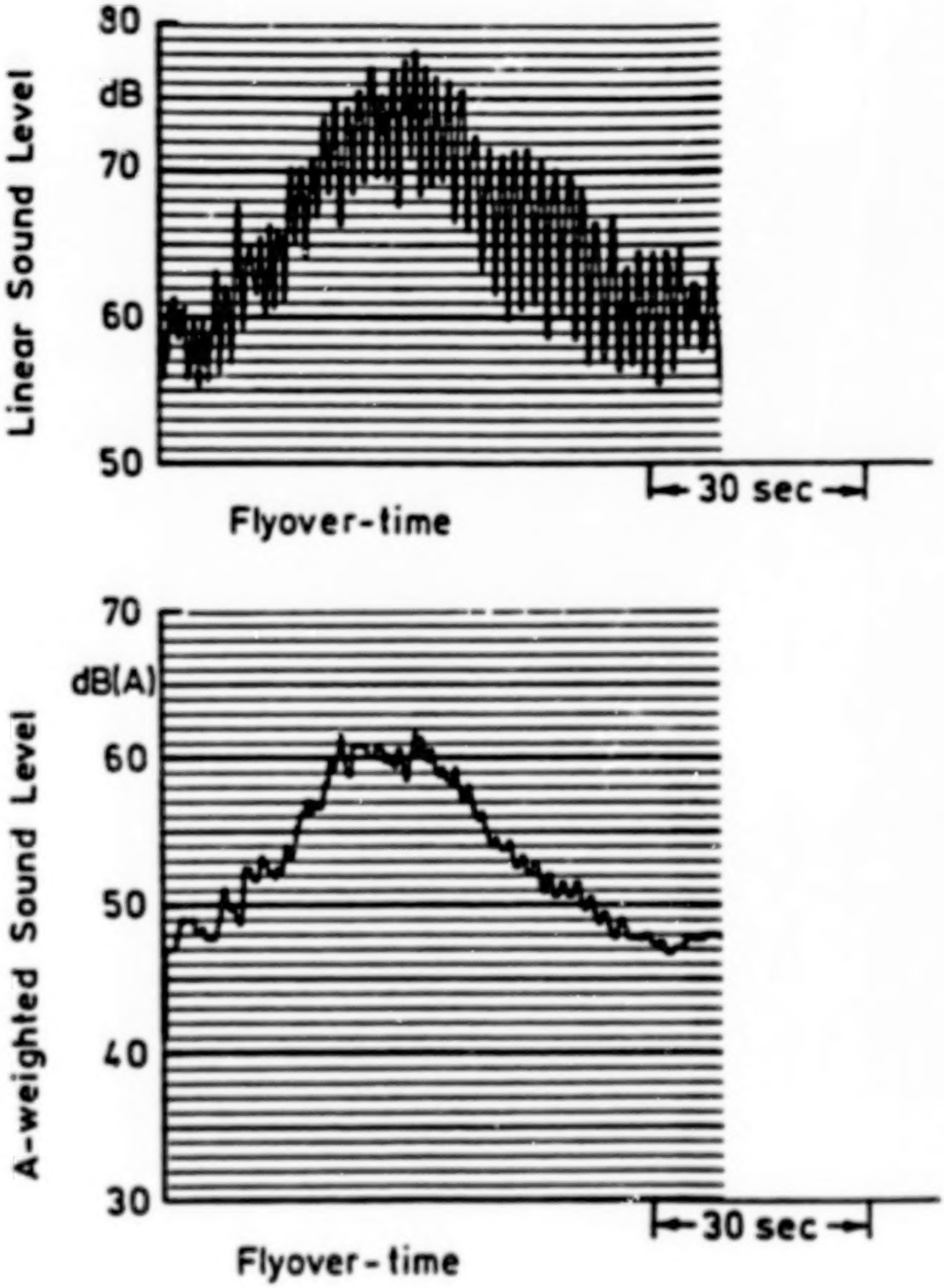
pkt	ppp	tt	tftf	rf	td	tddiff	h.ue.gr	dt/100m	bemerk.
1	1012.6	5.0	4.0	86	2.8	2.2	0	0.00	
2	1006.0	6.2	3.9	69	1.0	5.2	54	2.22	
3	996.0	7.1	4.2	63	0.5	6.6	136	1.10	
4	982.0	7.1	4.1	62	0.3	6.8	253	0.00	
5	975.0	7.3	4.0	59	-0.2	7.5	311	0.34	
6	960.0	6.5	3.5	61	-0.4	6.9	439	-0.63	
7	947.0	5.7	3.0	64	-0.5	6.2	550	-0.72	
8	917.0	3.8	1.1	62	-2.8	6.6	813	-0.72	
9	881.0	0.7	-0.8	76	-3.0	3.7	1136	-0.96	
10	820.0	-3.8	-4.3	91	-5.1	1.3	1631	-0.91	
11	801.0	-6.0	-6.5	90	-7.4	1.4	1892	-0.84	
12	780.0	-7.3	-7.9	87	-9.1	1.8	2100	-0.63	
13	753.0	-9.9	-9.9	100	-9.9	0.0	2373	-0.95	
14	740.0	-10.9	-10.9	100	-10.9	0.0	2500	-0.74	
15	730.0	-11.9	-12.0	98	-12.2	0.3	2612	-0.96	
16	721.0	-11.0	-12.4	57	-17.8	6.8	2700	0.94	eis
17	715.0	-10.0	-12.1	45	-19.8	9.8	2772	1.56	eis
18	704.0	-10.0	-12.2	43	-20.2	10.2	2892	0.00	eis
19	695.0	-10.2	-12.1	49	-18.8	8.6	2991	-0.20	eis
20	680.0	-10.7	-11.3	77	-14.0	3.3	3159	-0.30	eis
21	667.0	-11.3	-11.8	79	-14.3	3.0	3307	-0.41	eis
22	650.0	-10.0	-12.1	47	-19.1	9.1	3412	1.24	eis
23	590.0	-14.8	-15.7	64	-20.1	5.3	4245	-0.58	eis

APPENDIX II

As measured overall noise level time histories

Type of Aircraft: Metro III Flyover No.: 1

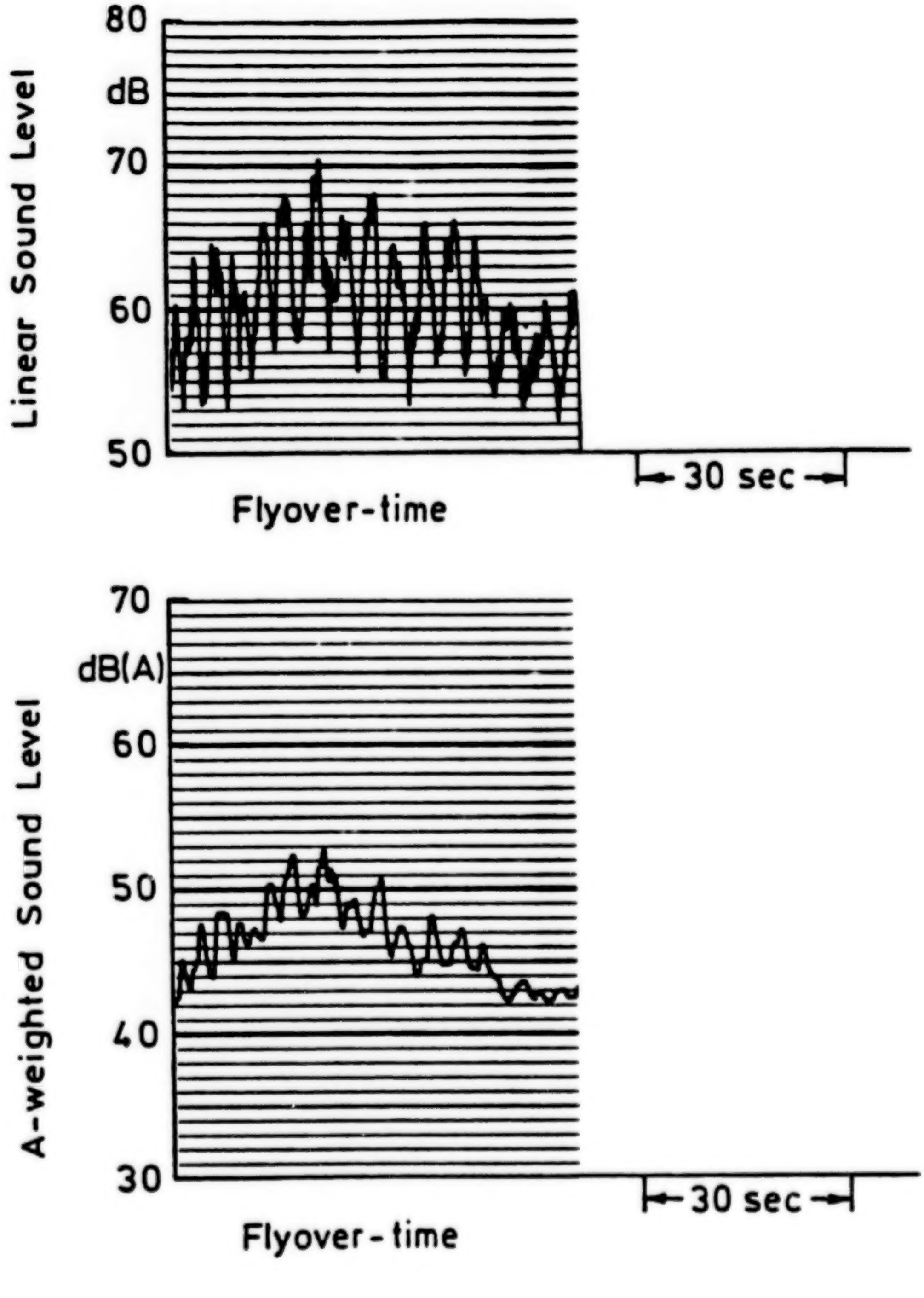
Microphone Position: Ground-board Microphone



As measured overall level time-histories (Metro III climb out)

Type of Aircraft: Metro III Flyover No.: 2

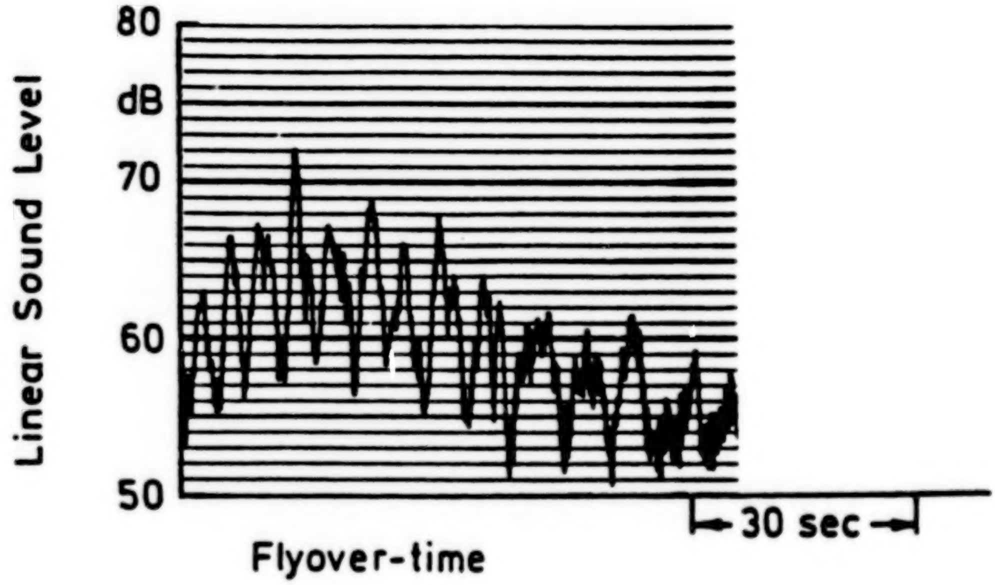
Microphone Position: Ground-board Microphone

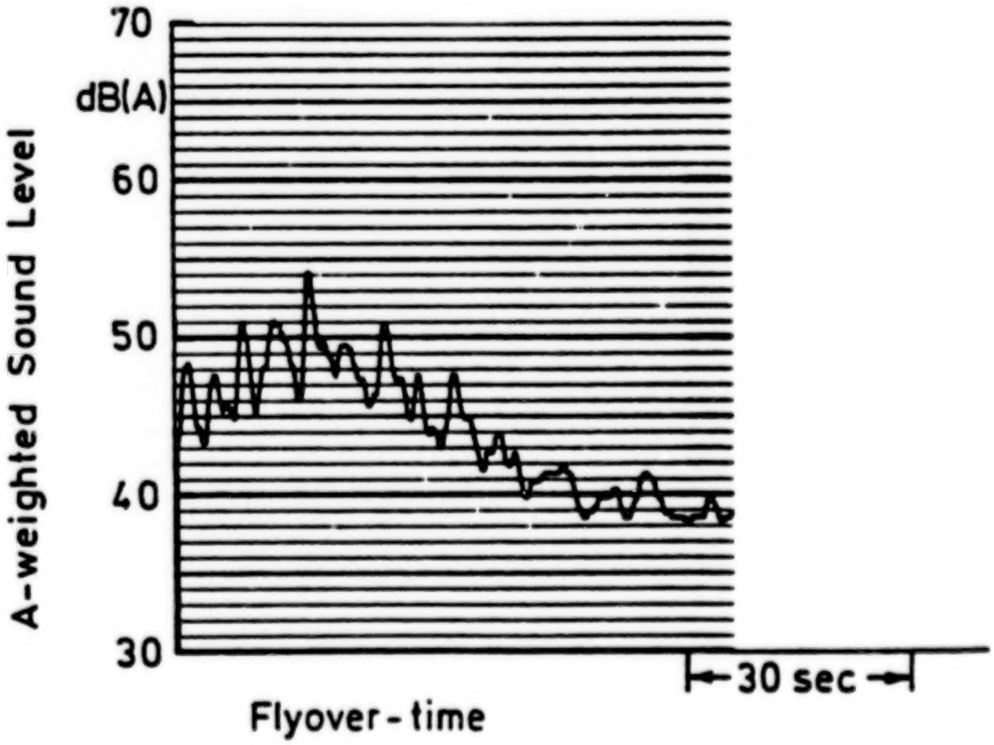


As measured overall level time-histories (Metro III/ No. 2, flight height: 17000 ft)

Type of Aircraft: Metro III Flyover No.: 3

Microphone Position: Ground-board Microphone

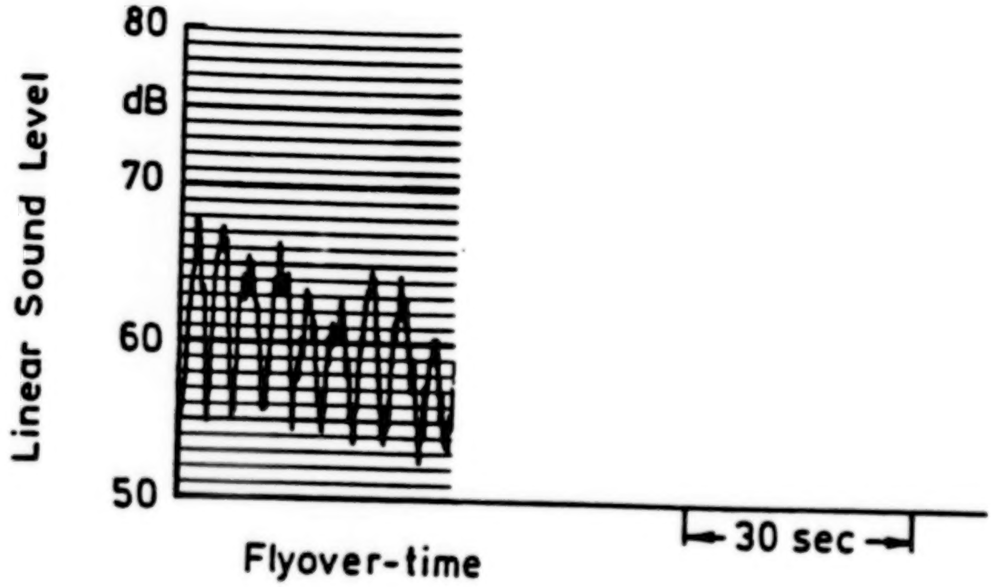


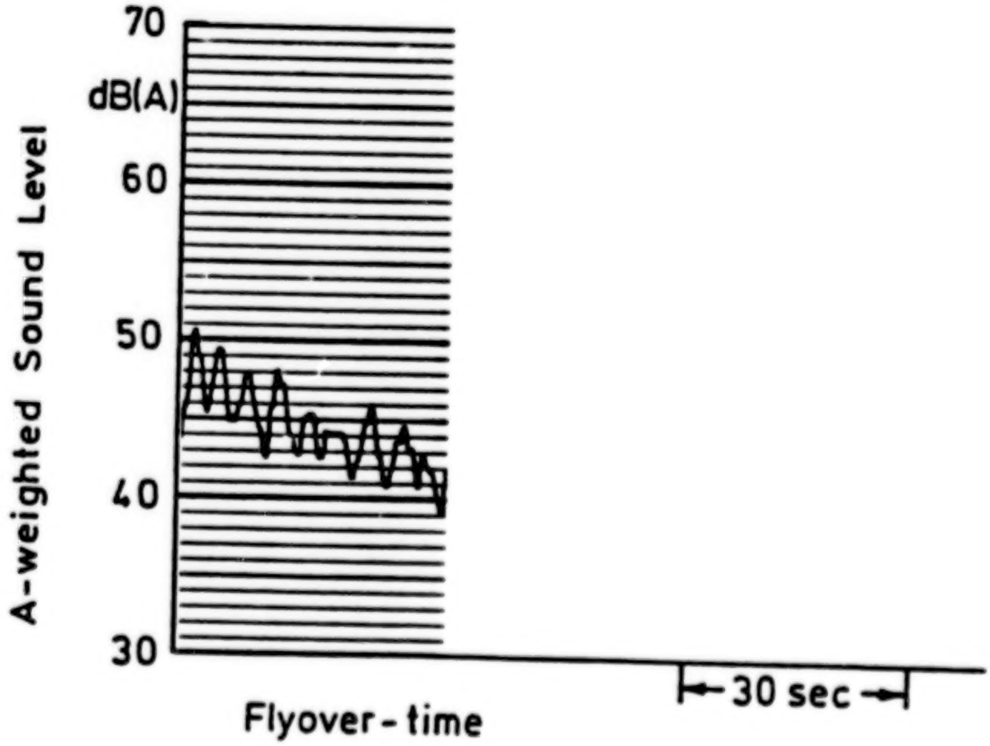


As measured overall level time-histories (Metro III/ No. 3, flight height: 17000 ft)

Type of Aircraft: Metro III Flyover No.: 4

Microphone Position: Ground-board Microphone

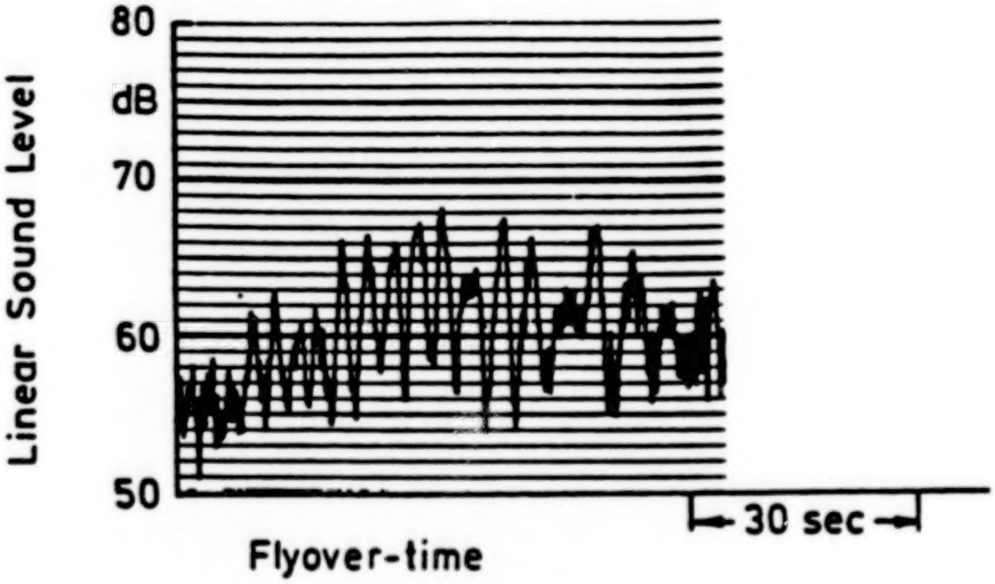


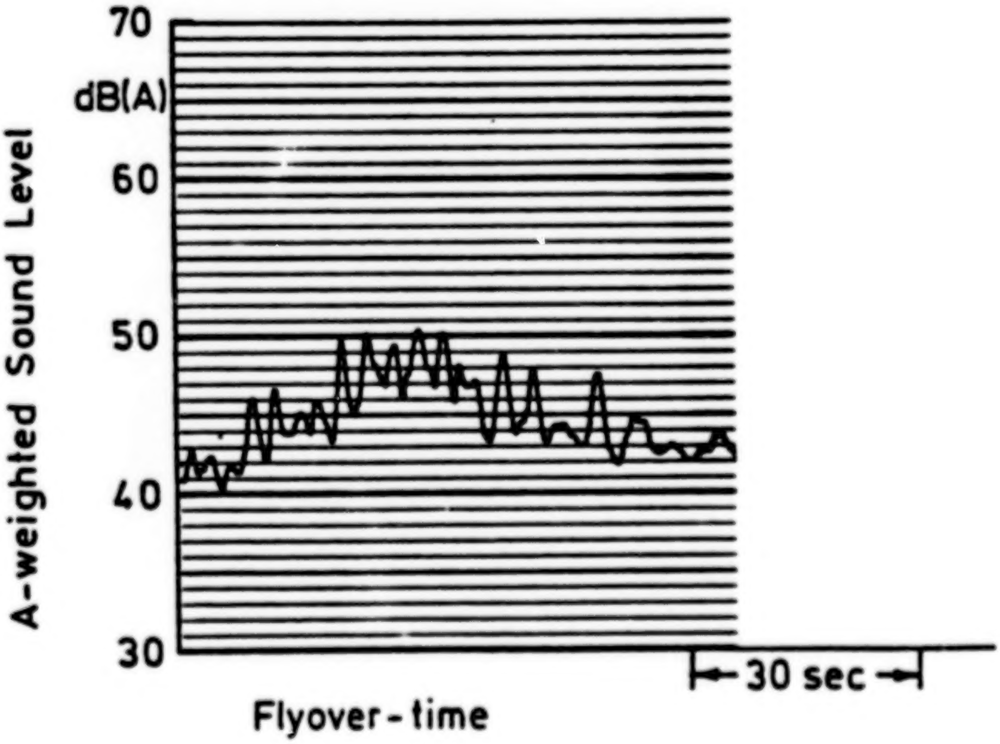


As measured overall level time-histories (Metro III/ No. 4, flight height: 19000 ft)

Type of Aircraft: Metro III Flyover No.: 5

Microphone Position: Ground-board Microphone

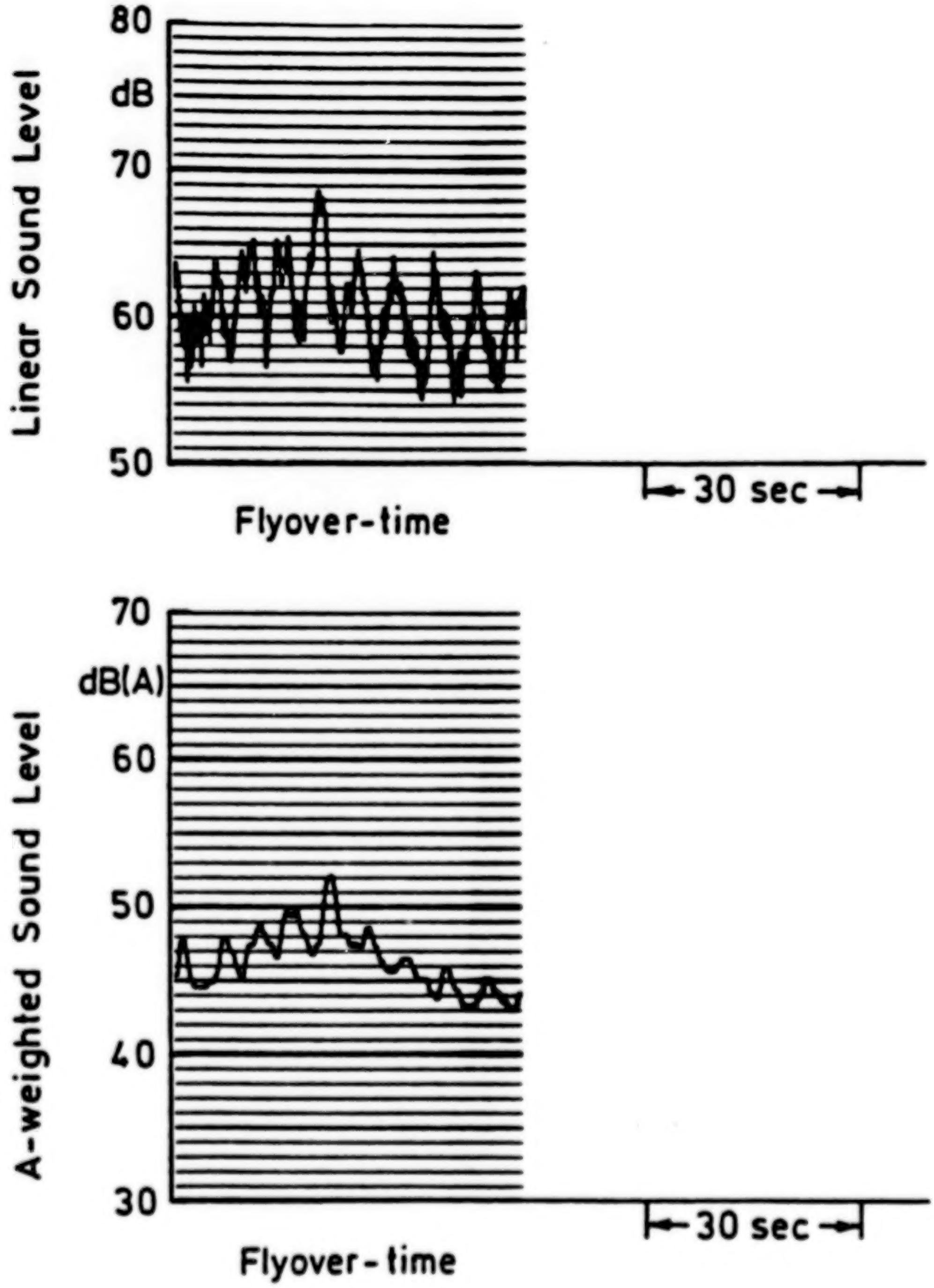




As measured overall level time-histories (Metro III/ No. 5, flight height: 19000 ft)

Type of Aircraft: Metro III Flyover No.: 6

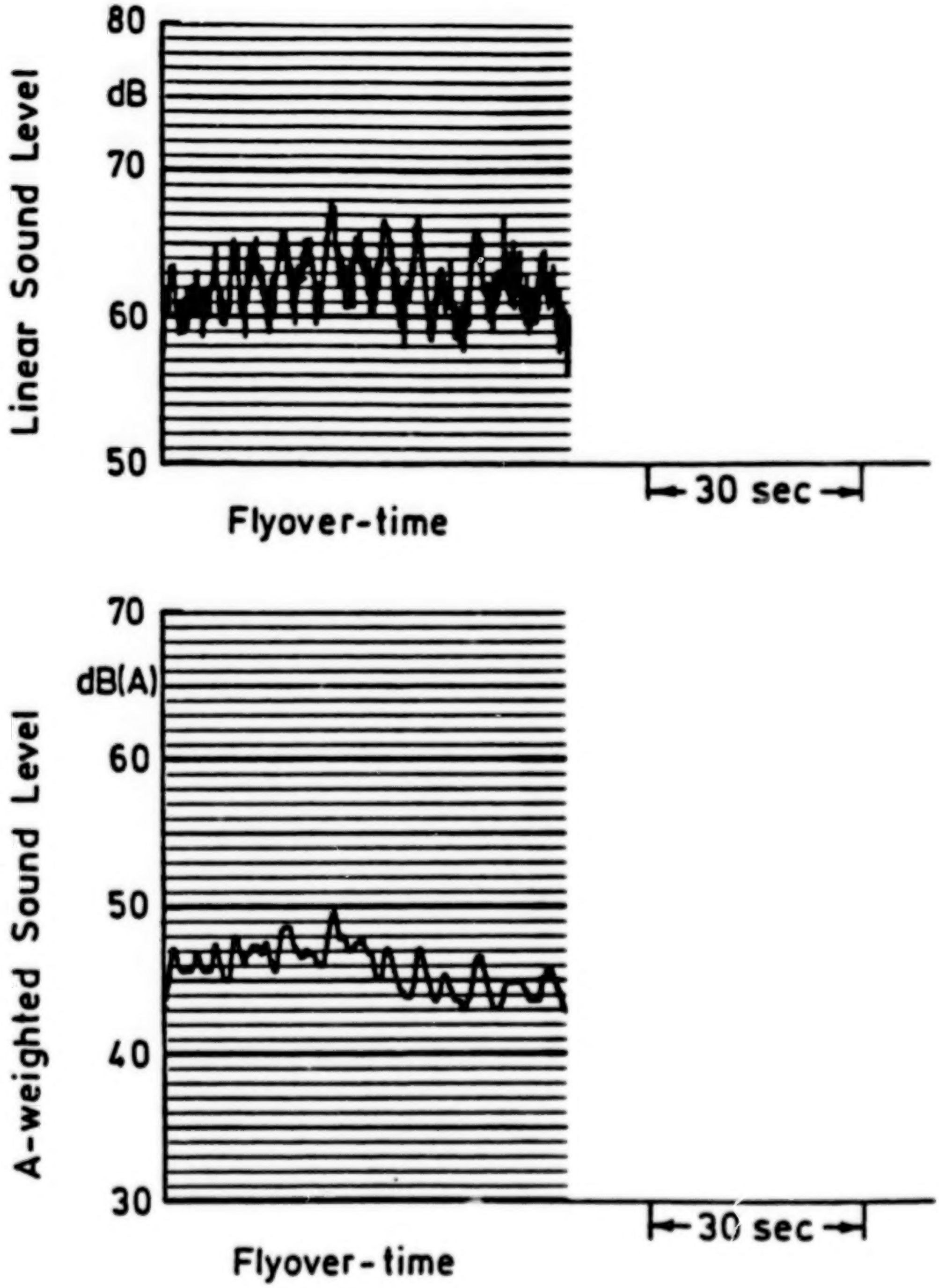
Microphone Position: Ground-board Microphone



As measured overall level time-histories (Metro III/ No. 6, flight height: 21000 ft)

Type of Aircraft: Metro III   Flyover No.: 7

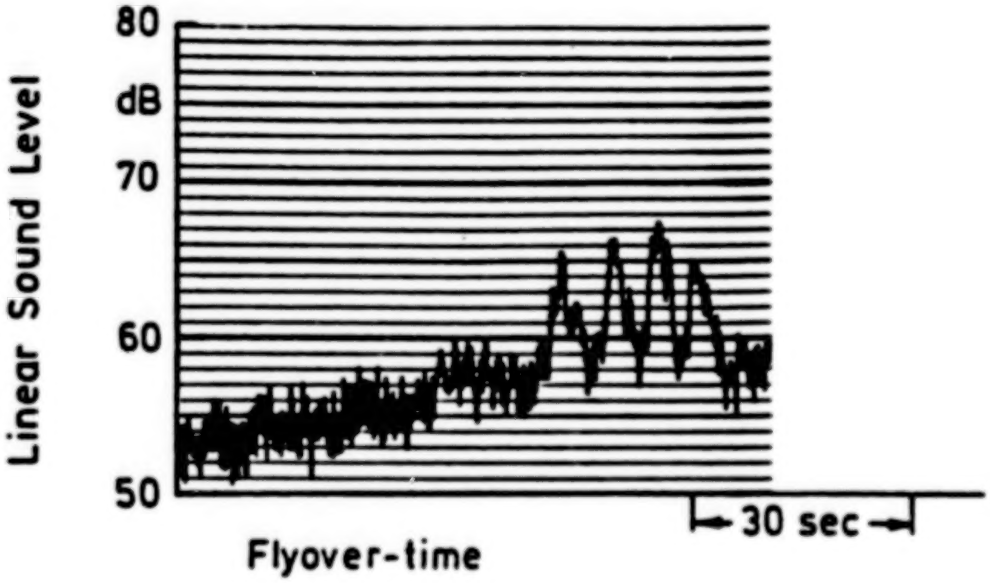
Microphone Position: Ground-board Microphone

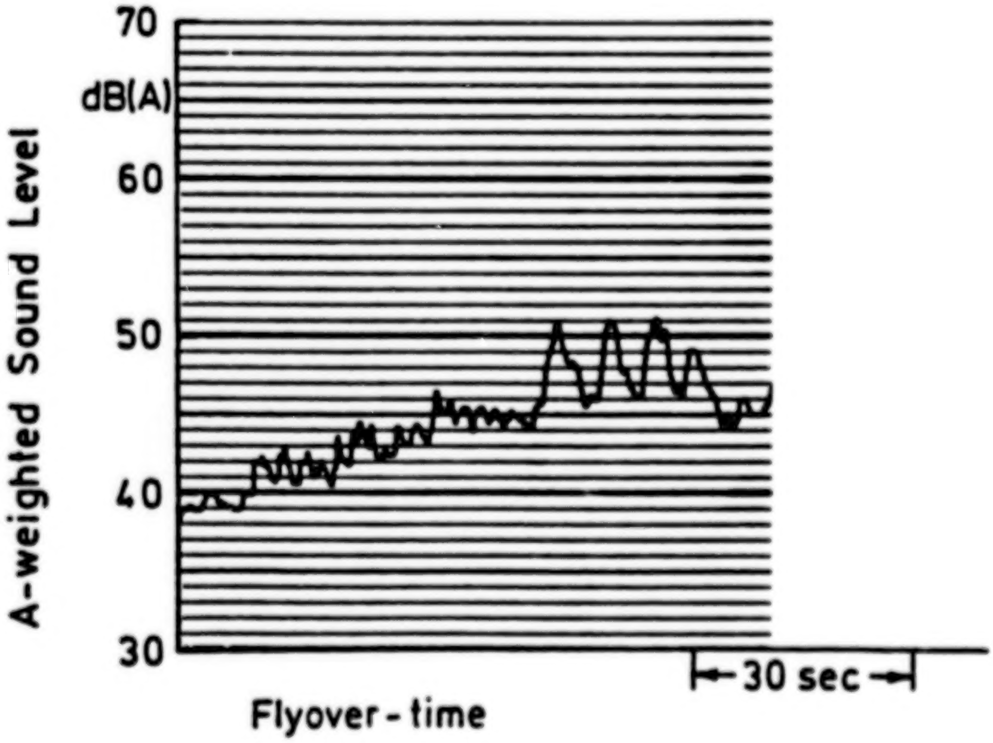


As measured overall level time-histories (Metro III/ No. 7, flight height: 21000 ft)

Type of Aircraft: Fokker 50 Flyover No.: 8

Microphone Position: Ground-board Microphone

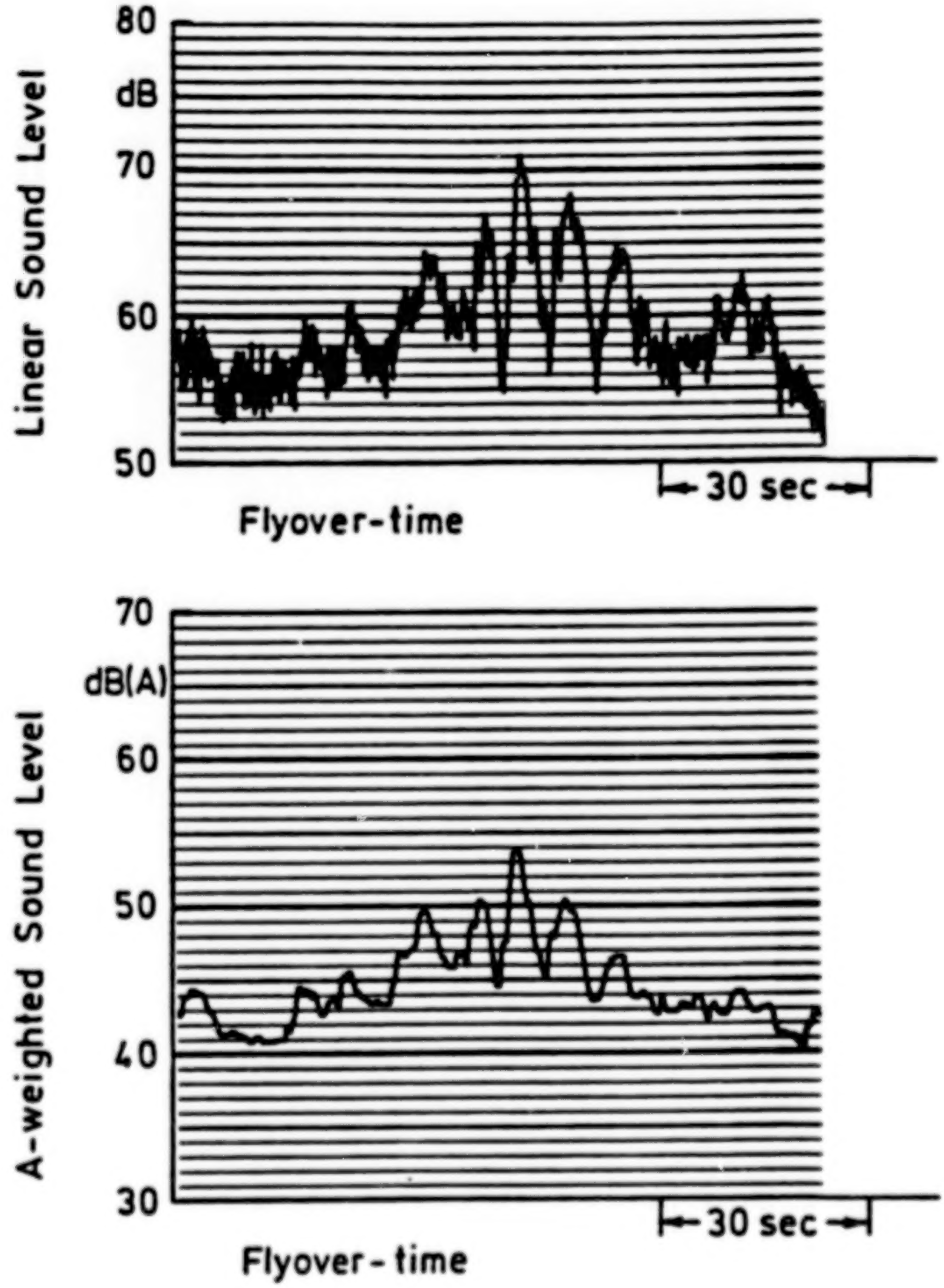




As measured overall level time-histories (Fokker 50/ No. 8, flight height: 17000 ft)

Type of Aircraft: Fokker 50   Flyover No.: 9

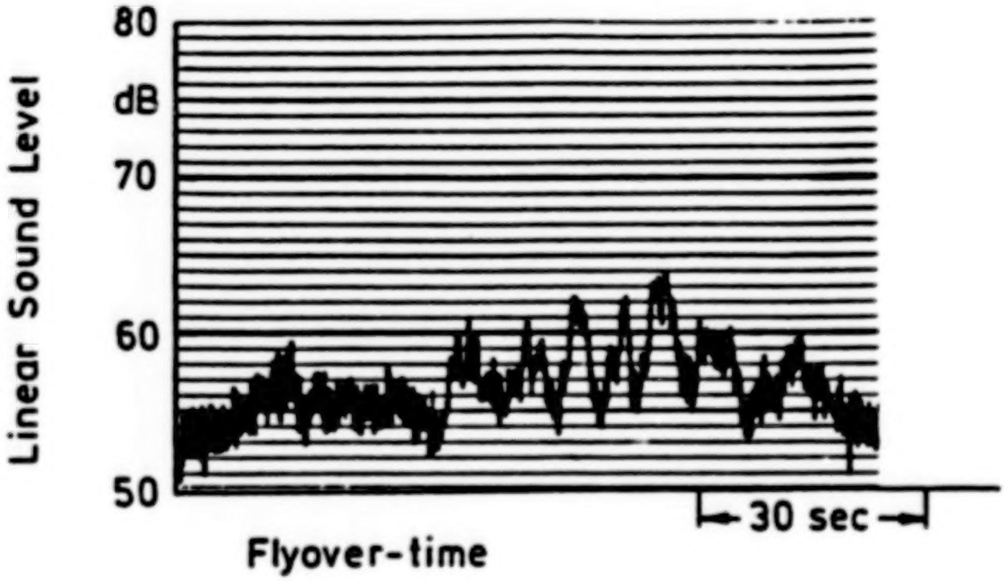
Microphone Position: Ground-board Microphone

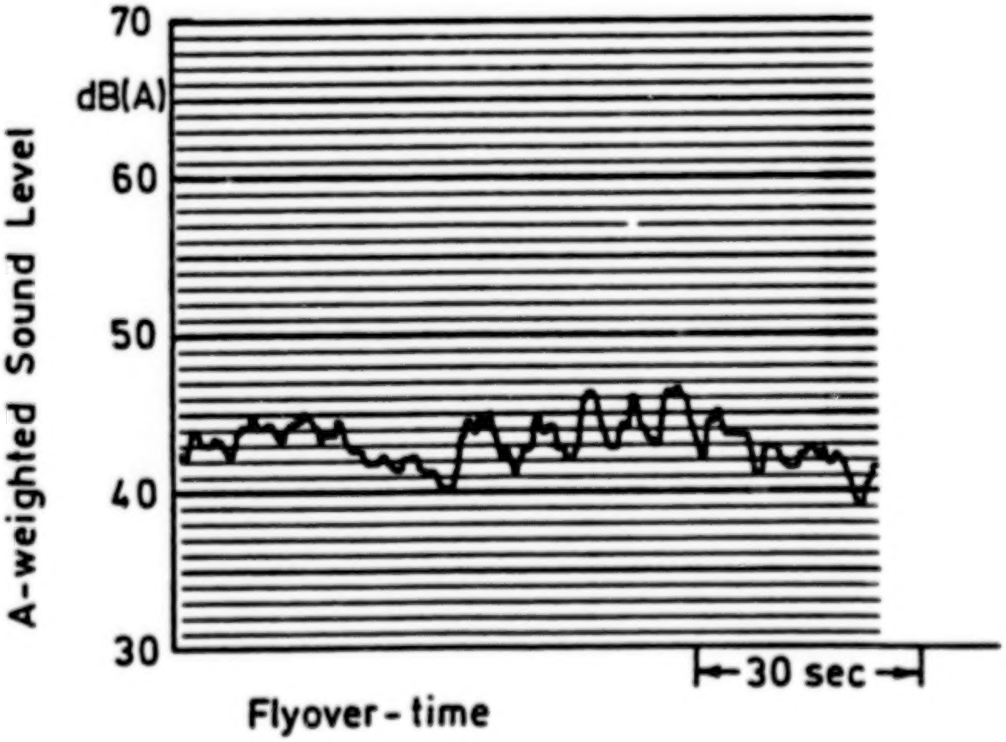


As measured overall level time-histories (Fokker 50/ No. 9, flight height: 19000 ft)

Type of Aircraft: Fokker 50 Flyover No.: 10

Microphone Position: Ground-board Microphone

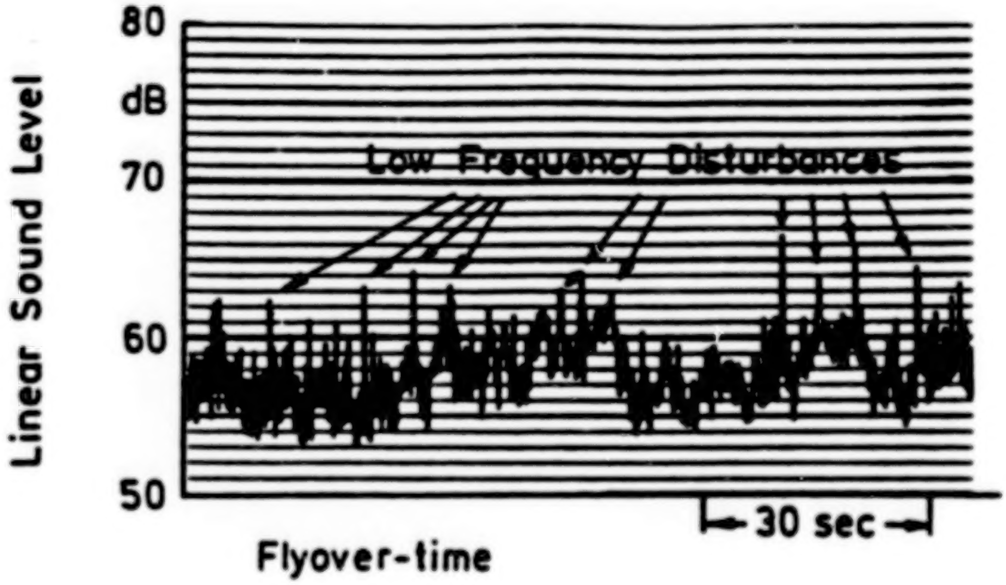


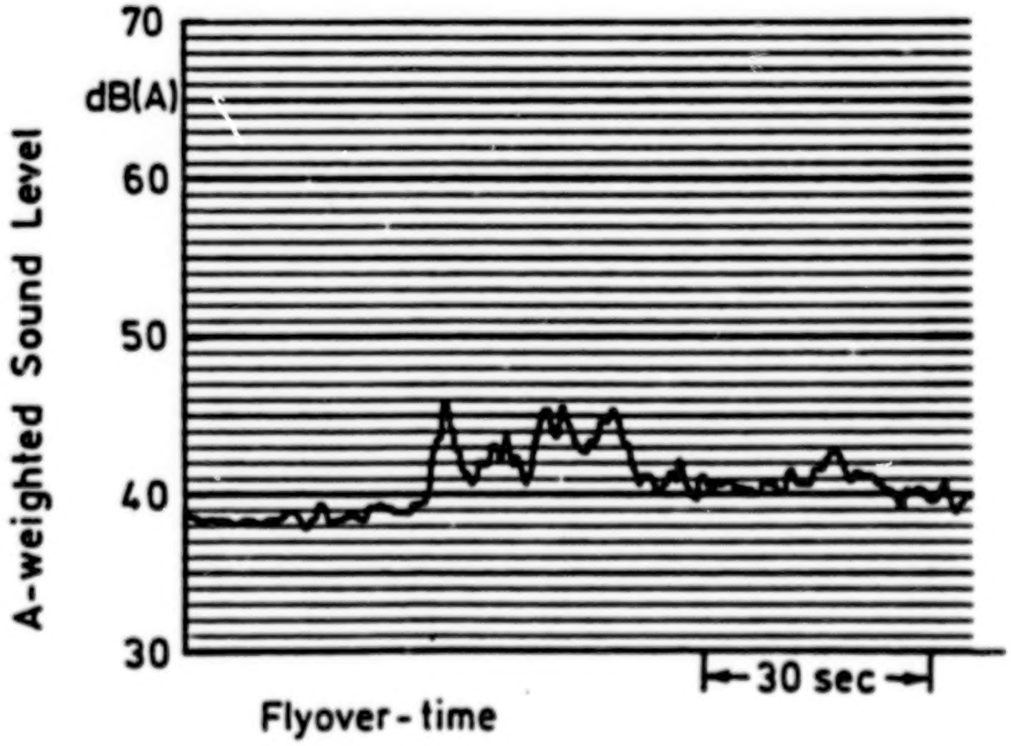


As measured overall level time-histories (Fokker 50/ No. 10, flight height: 19000 ft)

Type of Aircraft: Fokker 50 Flyover No.: 11

Microphone Position: Ground-board Microphone

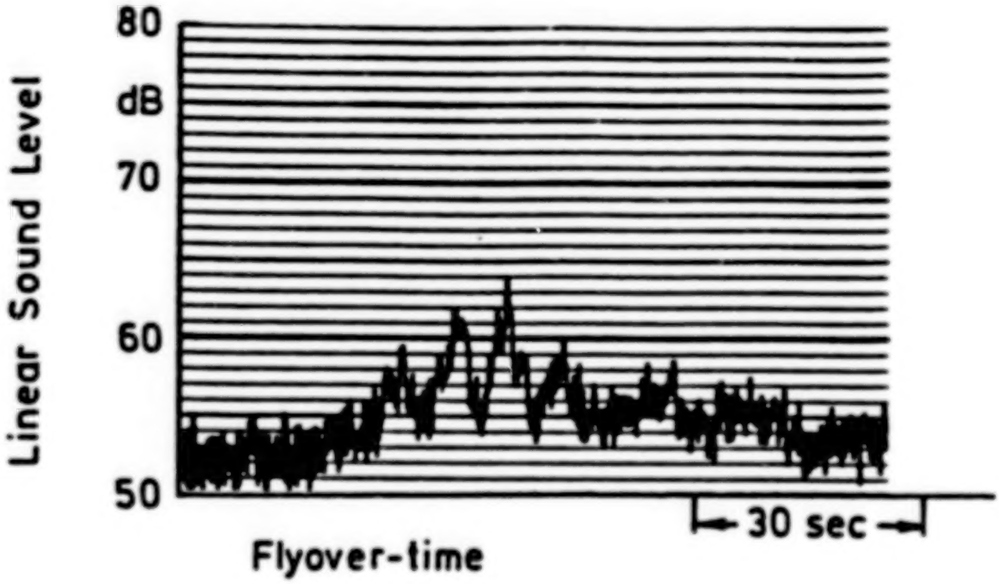


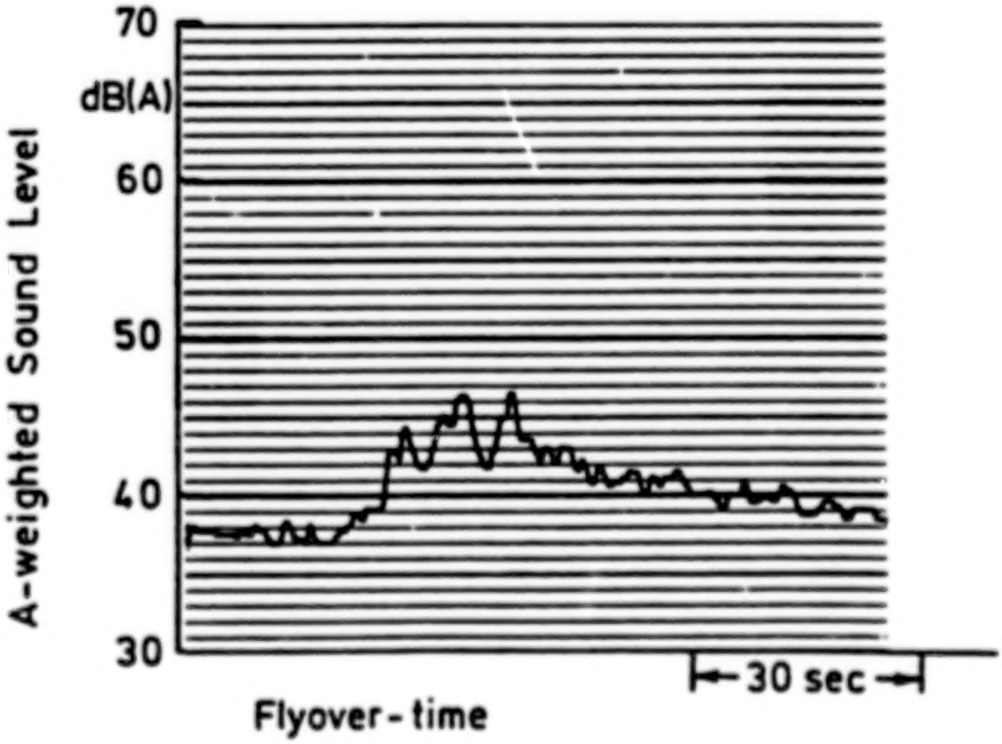


As measured overall level time-histories (Fokker 50/ No. 11, flight height: 21000 ft)

Type of Aircraft: Fokker 50 Flyover No.: 12

Microphone Position: Ground-board Microphone





As measured overall level time-histories (Fokker 50/ No. 12, flight height: 21000 ft)

BERICHT
ÜBER GERÄUSCHMESSUNGEN AN TURBOPROP-FLUGZEUGEN BEI VERSCHIEDENEN ÜBERFLUGHÖHEN

REPORT
ABOUT NOISE MEASUREMENTS OF TURBOPROP AIRPLANES AT DIFFERENT OVERFLIGHT ELEVATIONS*

Dipl. -Ing. Müller
The Landesanstalt für Umwelt

*English translation of text is unavailable.

1. Veranlassung der Untersuchungen

Im Hinblick auf die Schaffung der ICAO-Zulassungskriterien für Prop-Fan-Flugzeuge wurde die HLfU vom HeMUR mit Schreiben IIB31 - 53 e 219 - 1503/88 vom 21.09.88 beauftragt, die Geräuschimmissionen einschließlich Frequenzbewertung von bereits im Betrieb befindlichen Turboprop-Flugzeugen zu erfassen.

Als Testflugzeuge kamen die Typen METRO III und Fokker 50 zum Einsatz, wobei der Meßort in den Flughöhen 5182, 5791 und 6401 m jeweils in nördlicher Richtung und entgegengesetzt überflogen wurde.

2. Meßanordnung und Meßgeräte

Die Messung erfolgte am 30.04.89 von 0:00 bis ca. 2:00 Uhr im Bereich Griesheim westlich der Landesstraße 3303 (Lage des Meßpunktes vgl. Anlage 1).

Dabei wurden die Überfluggeräusche mit Schallpegelmessern der Klasse 1 nach DIN IEC 651 in 1,5 m bzw. 10 m Mikrofonhöhe erfaßt und auf Magnetband aufgezeichnet. Zur Frequenzbewertung wurde ein Terz/Oktavanalysator in linearer Mittelung mit 0,5 Sekunden Mittelungszeit eingesetzt.

3. Meßergebnisse

In der folgenden Tabelle sind die in beiden Mikrofonhöhen ermittelten Maximalpegel (Frequenzbewertung: A und Linear, Zeitbewertung: SLOW) gegenübergestellt.

Nr.	Flight Level	Maximaler Überflugpegel			
		L_{AS} max |dB(A)|		L_{LinF} max |dB|	
		1,5 m	10 m	1,5 m	10 m
1	Start	62,3	60,5	79,9	79,5
2	170	52,8	49,3	71,6	67,2
3	170	52,8	48,5	71,5	66,9
4	190	52,3	46,6	71	65,7
5	190	50,5	47,5	69	66,8
6	210	52,3	47,6	69,9	63,4
7	210	49,5	47,7	68,1	64,2
8	Start	56,9	55,5	73,4	72,2
9	170	54,2	47,7	71,5	66,5
10	170	49,8	48,2	66,1	62,4
11	190	55,4	48,6	73,9	65,2
12	190	47,6	46,7	65,5	63,8
13	210	46,8	45,2	63,9	62,1
14	210	46,6	42,3	62,5	57,2

Nr. 1-7 METRO III

Nr. 8-14 FOKKER 50

Flight Level 170 = 5182 m
Flight Level 190 = 5791 m
Flight Level 210 = 6401 m

In 10 m Höhe wurden bei allen Überflügen geringere A-Maximalpegel gemessen.

Diese Tatsache bestätigt die Aussagen im Forschungsbericht (DFVLR-FB81-28) der DLR über Interferenzwirkungen durch Bodenreflexion bei Fluglärmmessungen an Propellerflugzeugen. Danach sind bei Verwendung von Meßmikrofonen mit großem Bodenabstand im

zeitlichen Verlauf des Überflugs zeitweise Verfälschungen der Spektren von Signalquellen mit direkten Spektralanteilen (z.B. Propellerdrehklang) möglich.

Für den Fall, daß die Propeller-Grundfrequenz und ihre Harmonischen den A-bewerten Gesamtpegel bestimmen, sind auch Verfälschungen des maximalen Überflugspegels zu erwarten.

Die DLR führte parallel zur HLfU Überflugpegelmessungen mit einem Mikrofon am schallharten Boden und mit einem in 1,2 m Höhe angeordneten Mikrofon durch. Am schallharten Boden erhält man über den gesamten Frequenzbereich Schalldruckverdoppelung durch Reflexion. Der Vergleich der von der DLR ermittelten Maximalpegel mit den Meßwerten der HLfU läßt vermuten, daß auch in 1,5 m Mikrofonhöhe, zumindest für die Propeller-Grundfrequenz eine reflexionsbedingte Verstärkung vorlag.

Da in 1,5 m Mikrofonhöhe der vom Standpunkt der Immissionsmessung ungünstigere Fall (Pegelerhöhung durch Reflexion) vorliegt, wird die Darstellung der Ergebnisse von Terzanalysen auf die in dieser Höhe ermittelten Meßwerte beschränkt. In den Anlagen 2-15 sind der zeitliche Verlauf der Terzpegel, sowie die linearen und A-bewerteten Summenpegel für die einzelnen Überflüge grafisch dargestellt. Dabei folgen die einzelnen Spektren im Abstand von ca. 0,5 sec. nacheinander.

Bei beiden Flugzeugtypen ergibt sich, wie auch durch schmalbandige Analysen bestätigt, aus den Propellerblatt- und drehzahlen eine Propeller-Grundfrequenz von ca. 100 Hz. Während des Überflugs dominiert nicht nur diese eine Terzfrequenz. Die grafische Darstellung vedeutlicht den Dopplereffekt als Verschiebung der dominierenden Terzfrequenz im Verlauf des Überflugs.

Weiterhin sind bei allen Überflügen sowohl beim Summenpegel als auch in den einzelnen Terzbändern regelmäßige Pegelschwankungen festzustellen.

Die periodisch auftretenden Pegelschwankungen lassen den Schluß zu, daß es sich hierbei nicht um zufällige atmosphärische Störungen handelt, sondern um eine Schwebung, bedingt durch Drehzahldifferenzen der beiden Antriebspropeller.

Bei der Gegenüberstellung der maximalen Überflugpegel sind bei gleicher Flughöhe erhebliche Pegelunterschiede festzustellen. Im Falle Überflug Nr. 4 traten höherfrequente Spektralanteile auf (vgl. Anlage 5), die vermutlich als Fremdgeräusche zu dem höheren Summenpegel führen. Die Pegelunterschiede bei Überflug Nr. 9, 10 und 11, 12 sind nicht durch Fremdgeräusche zu erklären. Es bleibt festzustellen, daß beim Überflug in nördlicher Richtung höhere Summen- und Terzpegel auftraten, wahrscheinlich aufgrund unterschiedlicher Ausbreitungsbedingungen. Die vom "Deutschen Wetterdienst" ermittelten meteorologischen Daten während der Überflüge liefern allerdings keine Erklärung für diese festgestellten Pegelunterschiede.

Die Anlagen 16-29 stellen für jeden Überflug das Spektrum mit der deutlichsten herausragenden Terz der Propeller-Grundfrequenz dar. Die Pegeldifferenzen zu den Nachbarterzen sind in der folgenden Tabelle herausgestellt.

<table>
<tr><th>Nr.</th><th>Flight Level</th><th colspan="3">herausragende Terz</th></tr>
<tr><th></th><th></th><th>f |Hz|</th><th>L |dB|</th><th>ΔL |dB|</th></tr>
<tr><td></td><td></td><td>80</td><td>57,6</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>19,4</td></tr>
<tr><td>1</td><td>Start</td><td>100</td><td>77,0</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>19,4</td></tr>
<tr><td></td><td></td><td>125</td><td>57,6</td><td></td></tr>
<tr><td></td><td></td><td>80</td><td>48,6</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>15,7</td></tr>
<tr><td>2</td><td>170</td><td>100</td><td>64,3</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>20,8</td></tr>
<tr><td></td><td></td><td>125</td><td>43,5</td><td></td></tr>
<tr><td></td><td></td><td>80</td><td>51,5</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>16,8</td></tr>
<tr><td>3</td><td>170</td><td>100</td><td>68,3</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>21</td></tr>
<tr><td></td><td></td><td>125</td><td>47,3</td><td></td></tr>
<tr><td></td><td></td><td>80</td><td>46,9</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>18</td></tr>
<tr><td>4</td><td>190</td><td>100</td><td>64,9</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>16,2</td></tr>
<tr><td></td><td></td><td>125</td><td>48,7</td><td></td></tr>
</table>

Nr.	Flight Level	herausragende Terz		
		f |Hz|	L |dB|	ΔL |dB|
5	190	80	48,1	
				18,3
		100	66,4	
				18,3
		125	48,1	
6	210	80	46,8	
				17,2
		100	64,0	
				17,0
		125	47,0	
7	210	80	48,5	
				16,5
		100	65,0	
				19,3
		125	45,7	
8	Start	80	54,4	
				16,5
		100	70,9	
				15,8
		125	55,1	

Nr.	Flight Level	herausragende Terz		
		f |Hz|	L |dB|	ΔL |dB|
		80	47,9	
				16,3
9	170	100	64,2	
				16,1
		125	48,1	
		80	49,4	
				12,6
10	170	100	62,0	
				13
		125	49,0	
		80	45,9	
				16
11	190	100	61,9	
				15,7
		125	46,2	
		80	45,3	
				12,6
12	190	100	57,9	
				14
		125	43,9	

Nr.	Flight Level	herausragende Terz		
		f |Hz|	L |dB|	ΔL |dB|
		80	42,4	
				7,7
13	210	100	50,1	
				10,6
		125	39,5	
		80	41,4	
				12,2
14	210	100	53,6	
				13,9
		125	39,7	

Nr. 1-7 METRO III
NR: 8-14 FOKKER 50

4. Vergleich zwischen METRO III und FOKKER 50

Auch wenn bei einzelnen Überflügen z.T. unerklärbare Abweichungen auftraten, so kann insgesamt vermutet werden, daß die maximalen Überflugpegel bei der Fokker 50 geringfügig niedriger als beim Metro III waren. Dies ist um so erstaunlicher, wenn man die Gewichts- und Leistungsdaten dieser beiden Flugzeuge vergleicht:

	METRO III	FOKKER 50
max. Abfluggewicht	6577 kg	18990 kg
Maschinenleistung	745,5 kW	1864 kW

In den Spektren beider Flugzeuge hebt sich die Terz der Propeller - Grundfrequenz deutlich aus den Nachbarterzen hervor. Auch dieses Herausragen ist bei der Fokker 50 - wie die letzte Tabelle zeigt - im Mittel um ca. 4 dB niedriger. Damit ist die Lästigkeit des Überflugsgeräuschs der Fokker 50 aufgrund der weniger ausgeprägten Einzeltonhaltigkeit etwas geringer.

Für die meisten Geräusche des täglichen Lebens ist der A-bewertete Schallpegel heute ein hinreichend genaues Maß zum Vergleich ihrer Lautstärken. In einigen Fällen, z.B. bei sehr tiefen Frequenzen, sind jedoch die dB(A)-Werte niedriger als die gehörrichtig ermittelten Lautstärkewerte. Da bei den Überflugpegeln beider Flugzeuge die A-bewerteten Gesamtpegel durch die herausragenden Frequenzanteile im Bereich 100 - 125 Hz geprägt sind, geben auch hier die A-Pegel einen ca. 10 dB zu niedrigen Pegel gegenüber den Lautstärkekurven (vgl. Anlage 30).

Wiesbaden, den 3 .08.1989

Der Bearbeiter

J. Henrizi

(J. Henrizi)

Hessische Landesanstalt
für Umwelt

(RD K. Müller)

Topographische Karte 1 : 25 000

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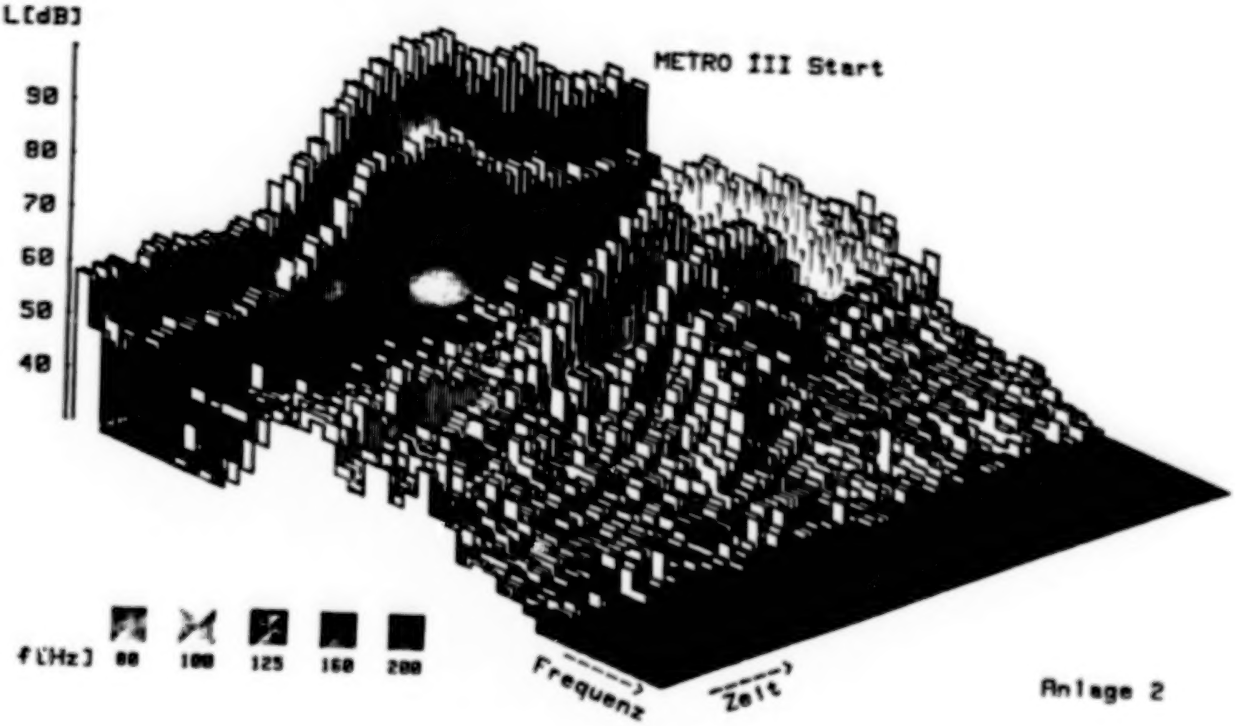
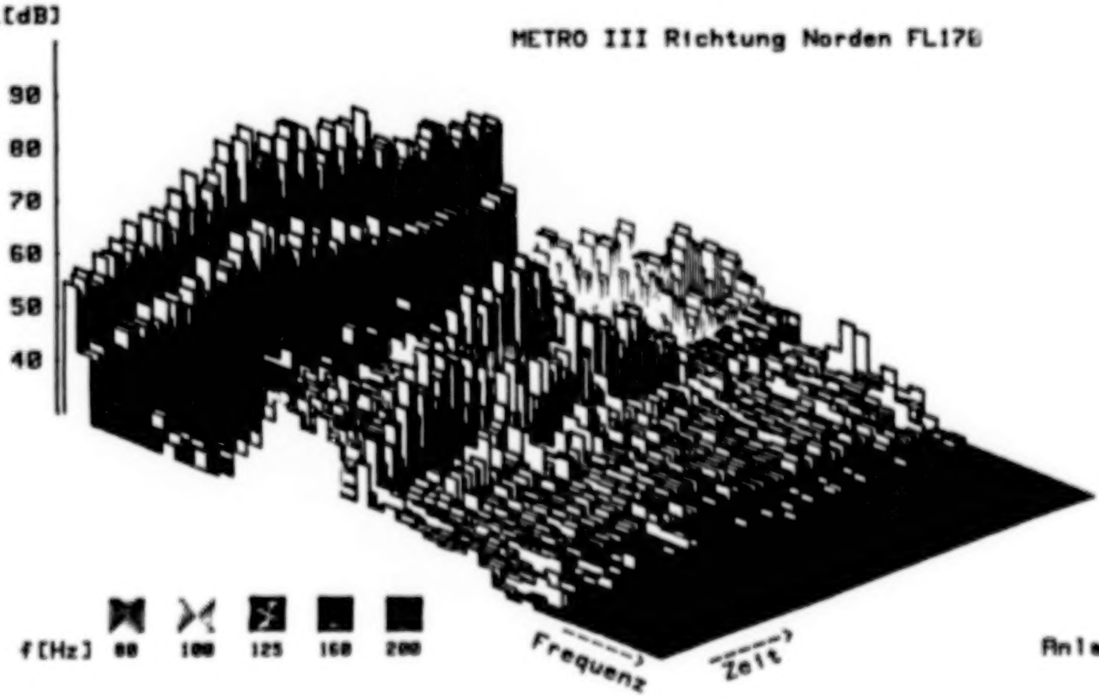
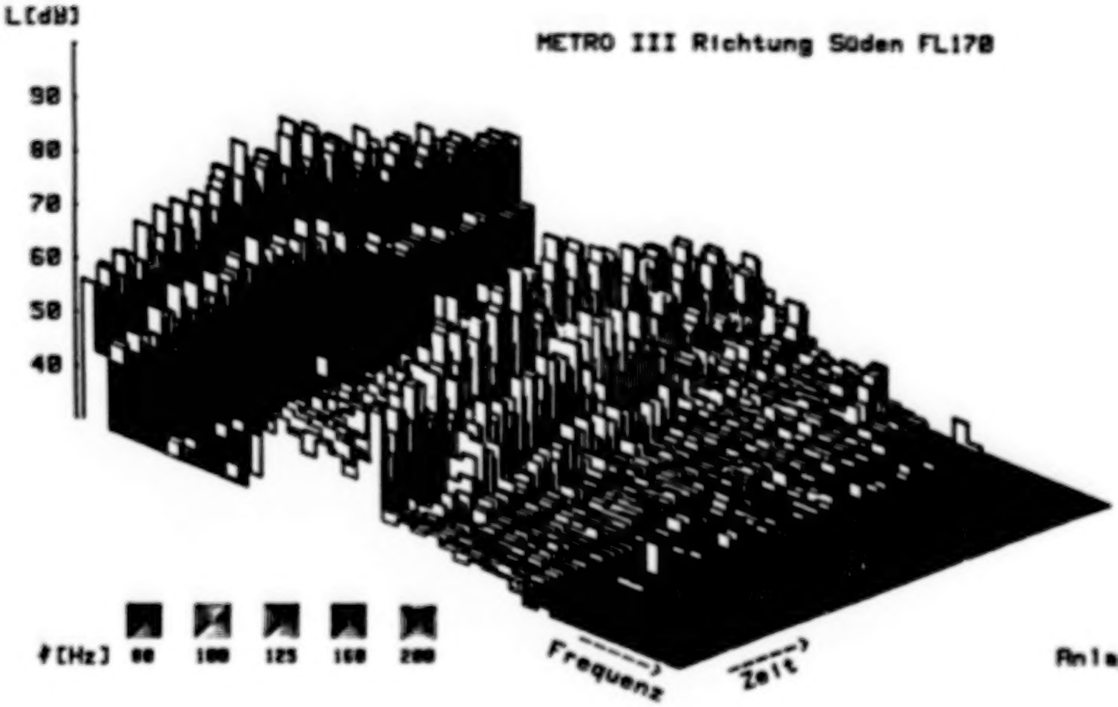


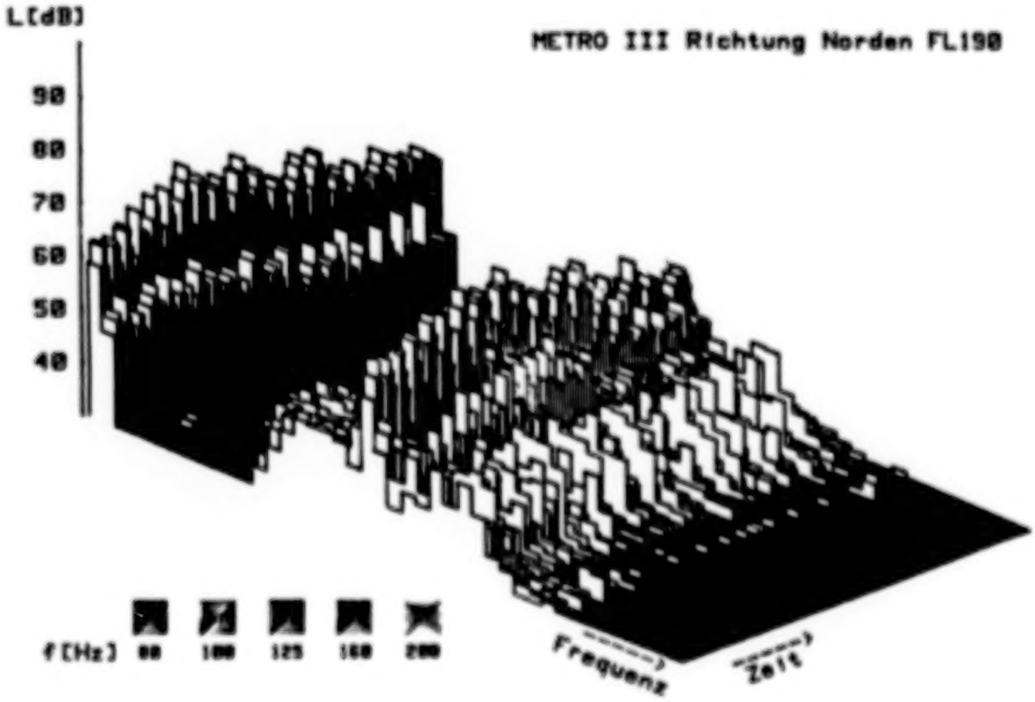
Anlage 2



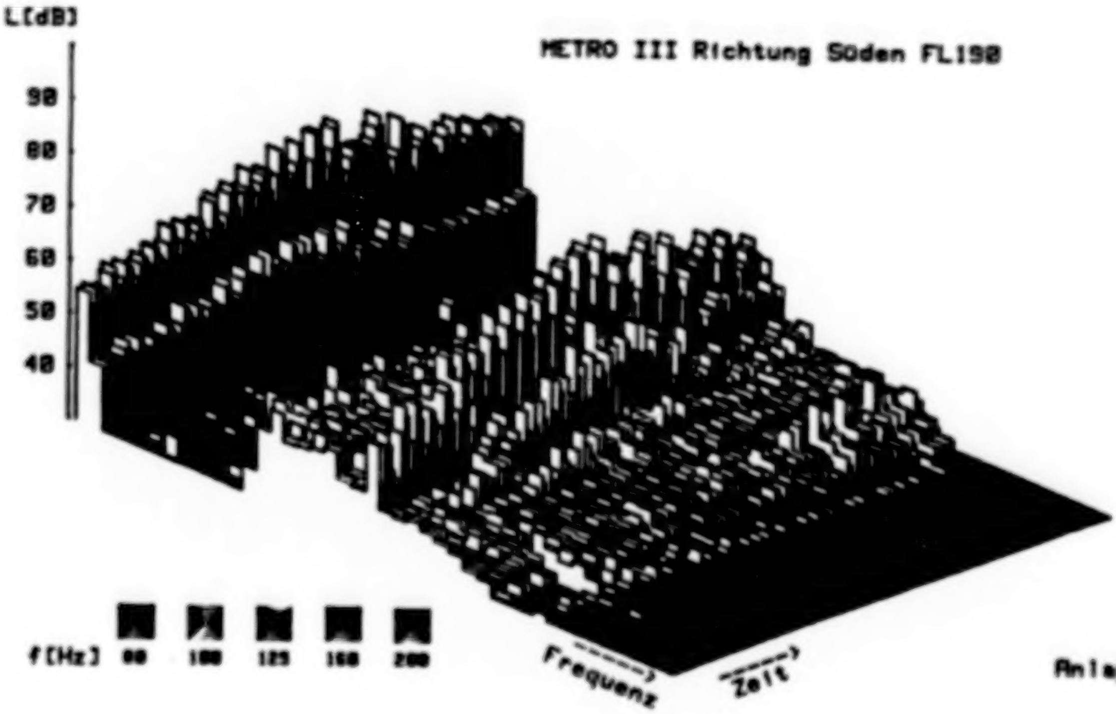
Anlage 3



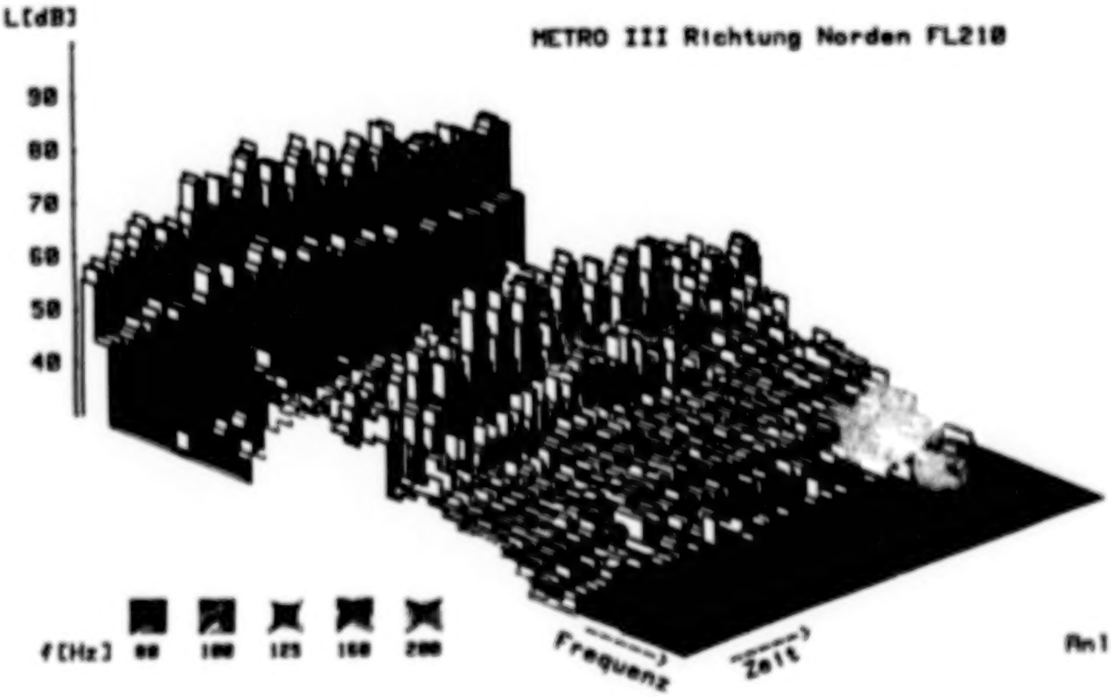
Anlage 4



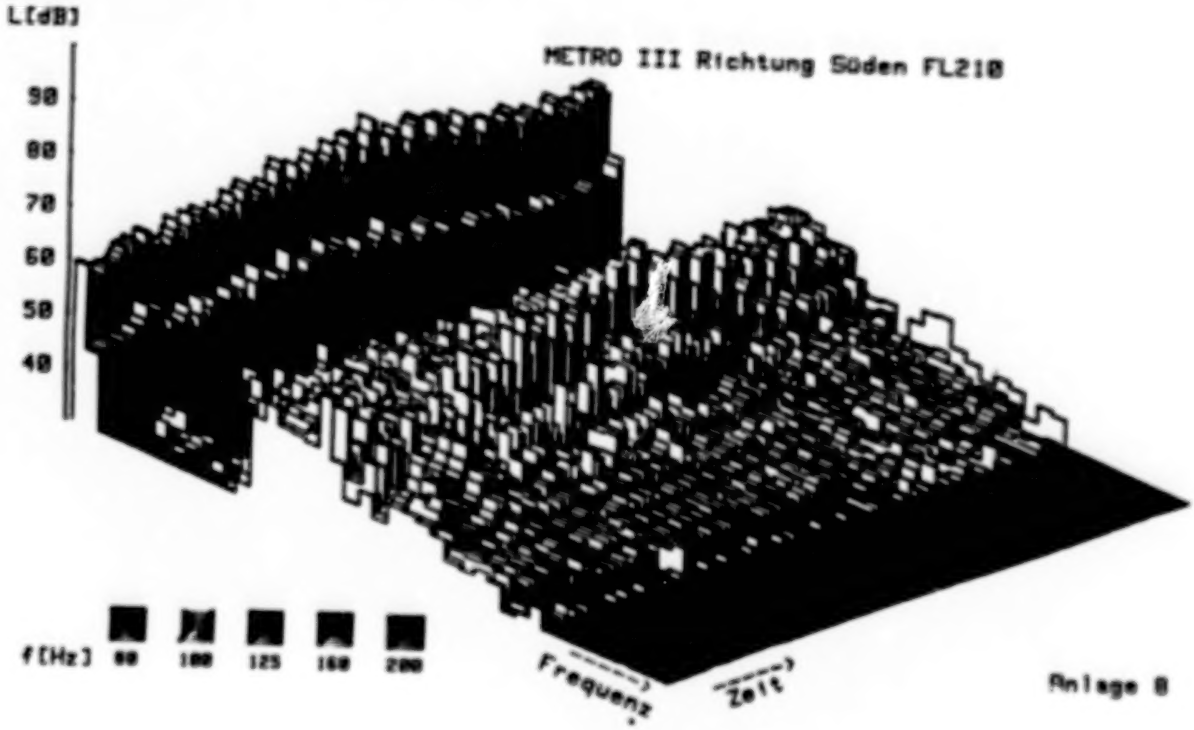
Anlage 5



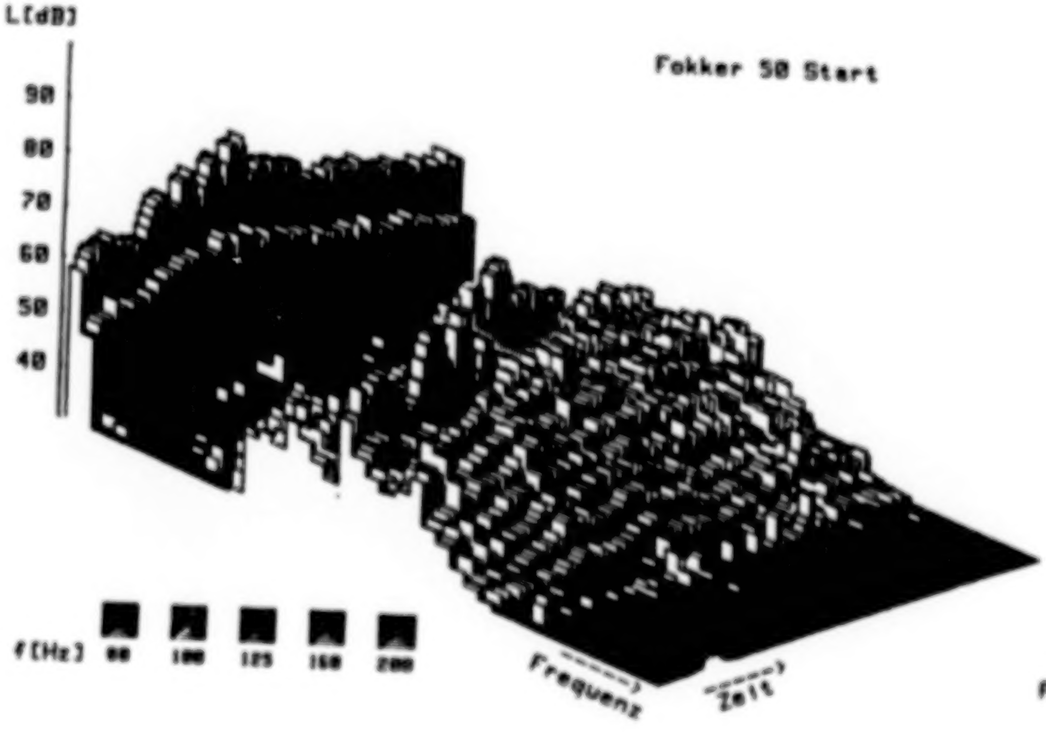
Anlage 6



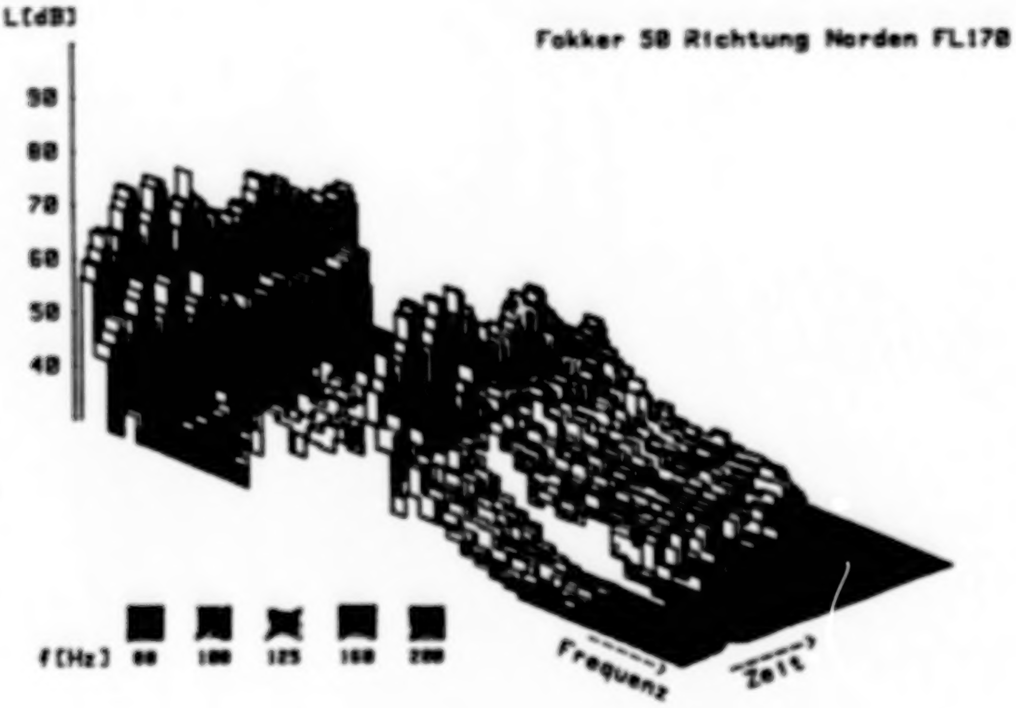
Anlage 7



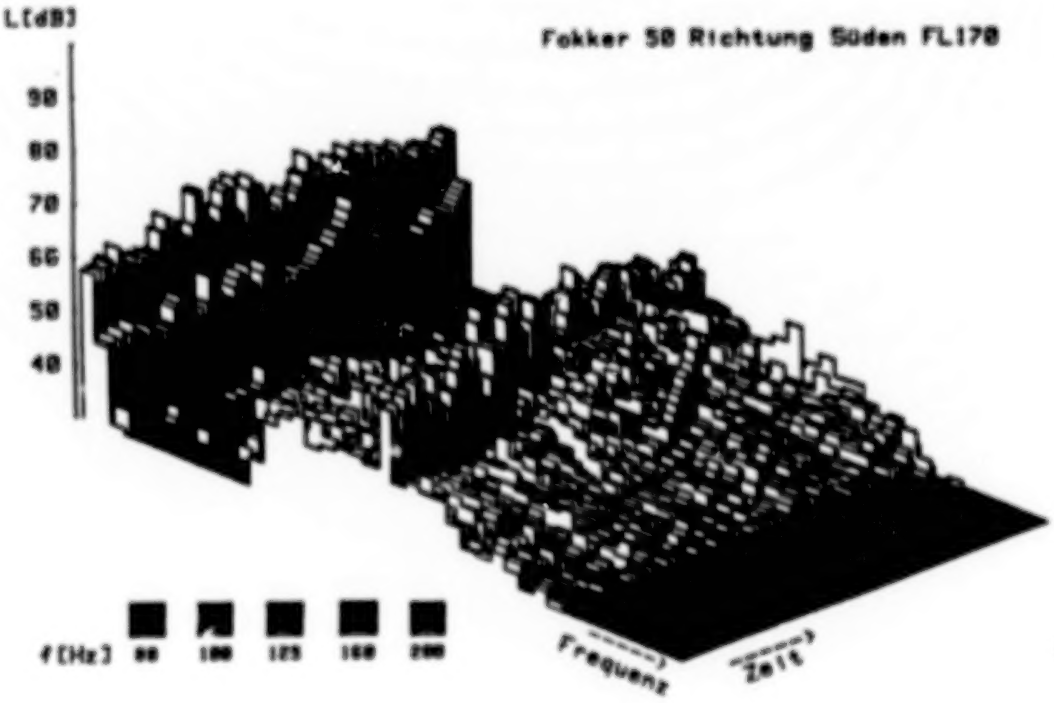
Anlage 8



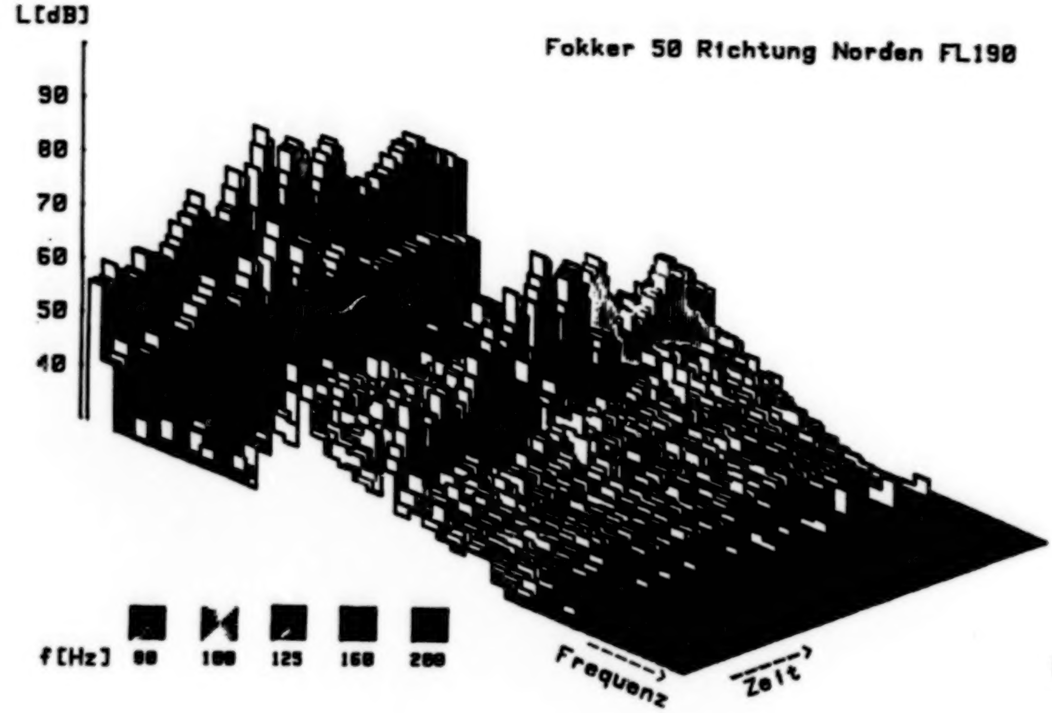
Anlage 9



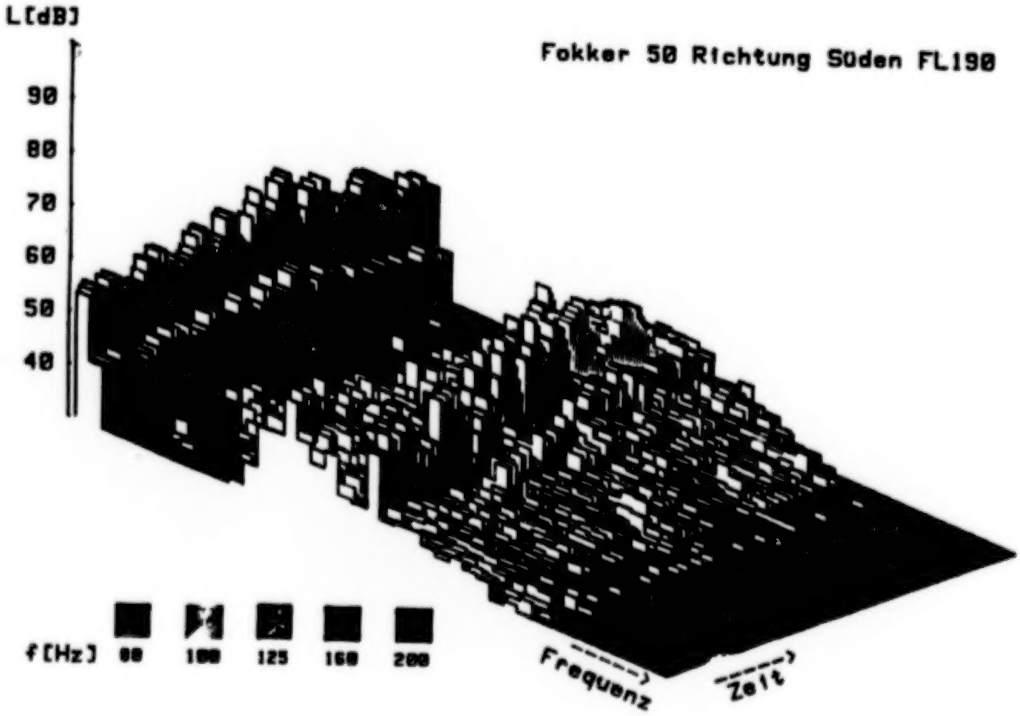
Anlage 10



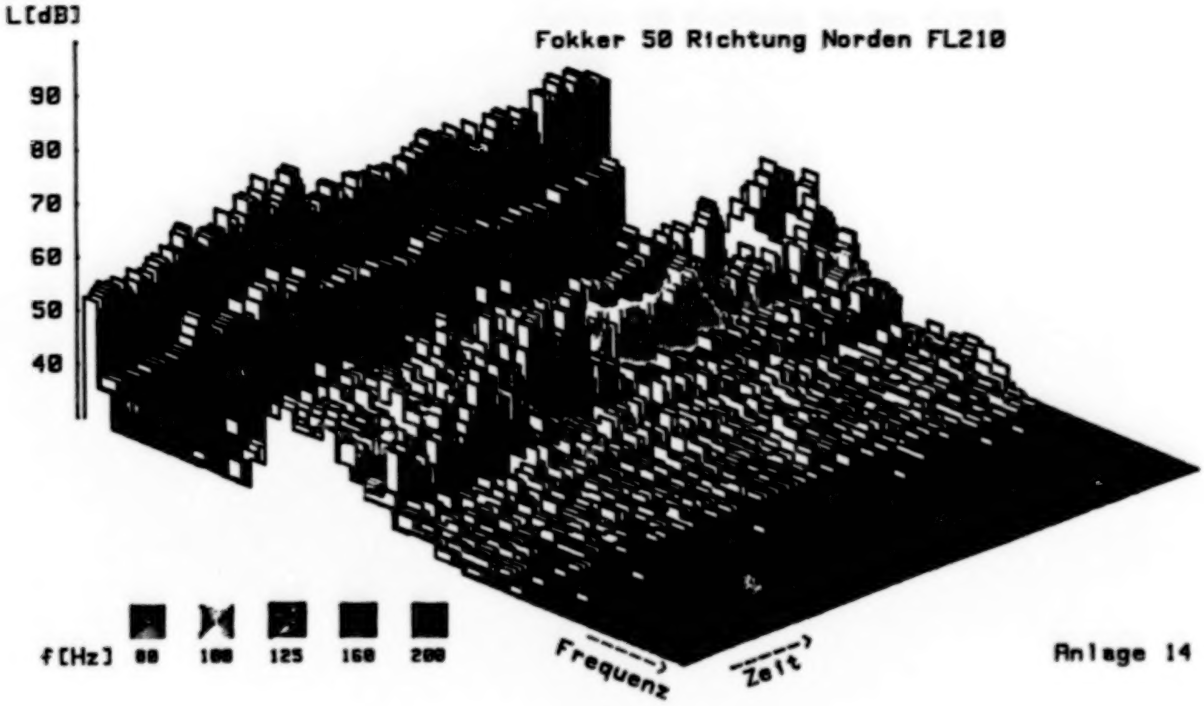
Anlage 11



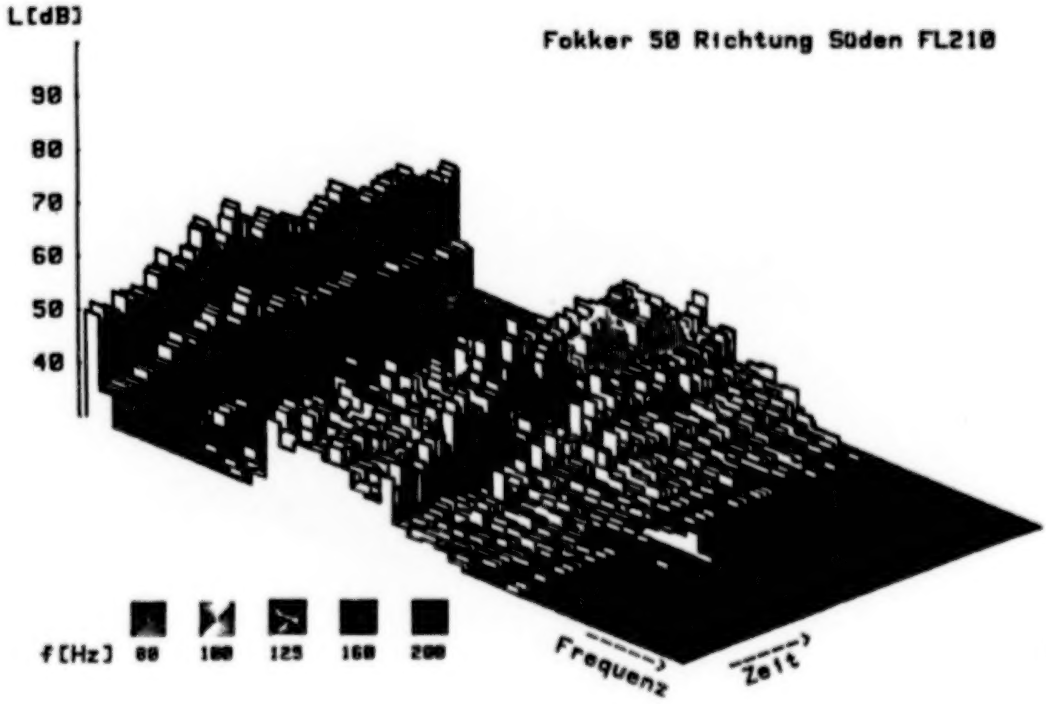
Anlage 12



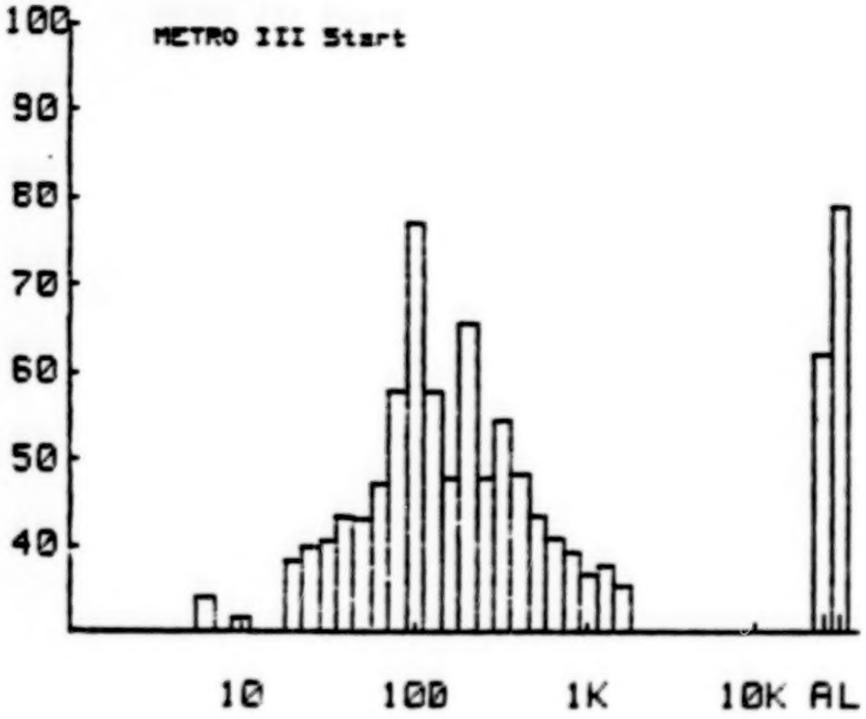
Anlage 13



Anlage 14

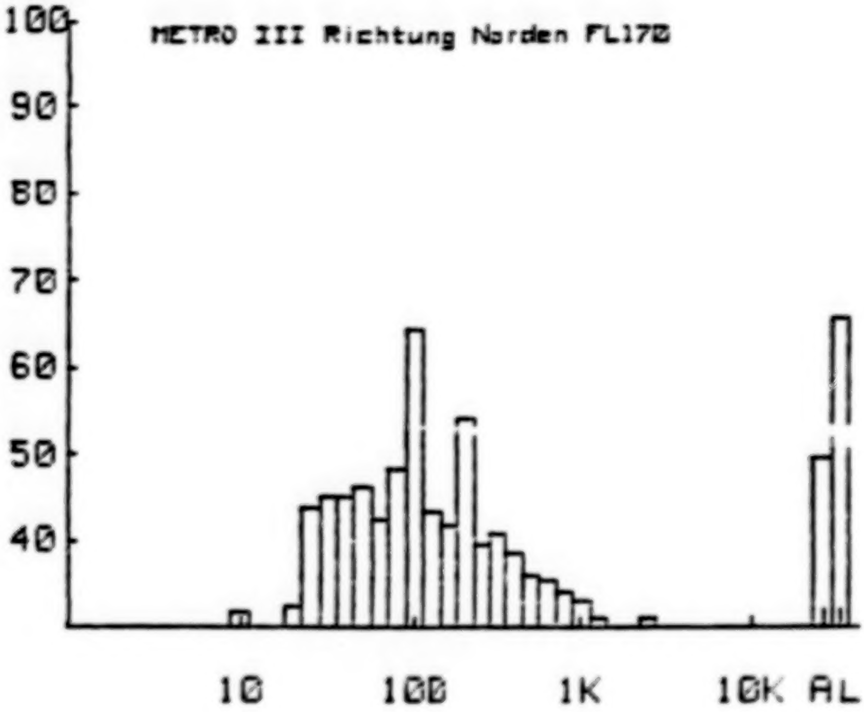


Anlage 15



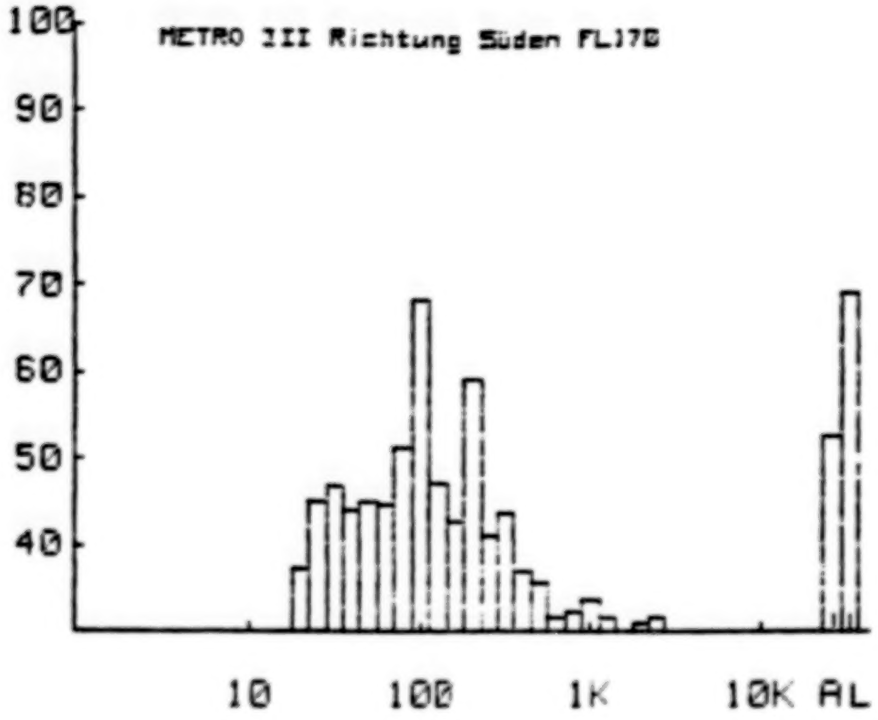
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	65.5
2.0	30.0	250.0	48.0
2.5	30.0	315.0	54.5
3.2	30.0	400.0	48.5
4.0	30.0	500.0	43.4
5.0	30.0	630.0	40.8
6.3	34.0	800.0	39.4
8.0	30.0	1000.0	36.7
10.0	31.8	1250.0	37.9
12.5	30.0	1600.0	35.1
16.0	30.0	2000.0	30.0
20.0	38.3	2500.0	30.0
25.0	40.0	3150.0	30.0
31.5	40.7	4000.0	30.0
40.0	43.6	5000.0	30.0
50.0	43.1	6300.0	30.0
63.0	47.4	8000.0	30.0
80.0	57.6	10000.0	30.0
100.0	77.0	12500.0	30.0
125.0	57.6	16000.0	30.0
160.0	47.9	20000.0	30.0
A-bew.	62.2		
Linear	79.0		

Anlage 16



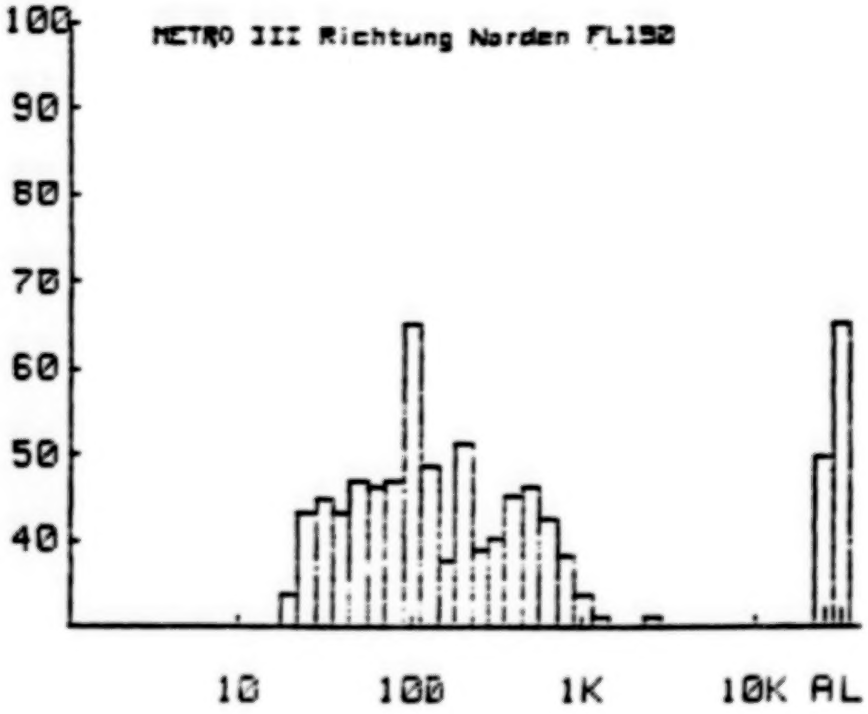
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	54.3
2.0	30.0	250.0	39.6
2.5	30.0	315.0	40.8
3.2	30.0	400.0	38.7
4.0	30.0	500.0	36.3
5.0	30.0	630.0	35.1
6.3	30.0	800.0	34.0
8.0	30.0	1000.0	33.0
10.0	31.8	1250.0	31.0
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	30.0
20.0	32.4	2500.0	31.0
25.0	43.9	3150.0	30.0
31.5	44.9	4000.0	30.0
40.0	44.9	5000.0	30.0
50.0	46.4	6300.0	30.0
63.0	42.5	8000.0	30.0
80.0	48.6	10000.0	30.0
100.0	64.3	12500.0	30.0
125.0	43.5	16000.0	30.0
160.0	42.0	20000.0	30.0
A-bew.	49.7		
Linear	65.8		

Anlage 17



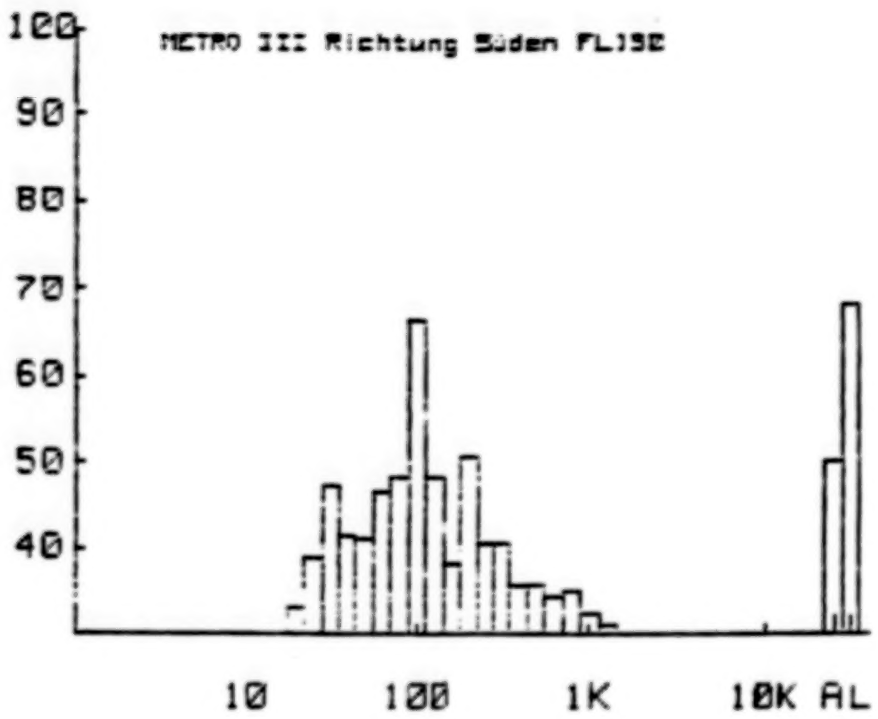
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	59.3
2.0	30.0	250.0	41.2
2.5	30.0	315.0	43.8
3.2	30.0	400.0	37.0
4.0	30.0	500.0	36.0
5.0	30.0	630.0	31.8
6.3	30.0	800.0	32.4
8.0	30.0	1000.0	33.5
10.0	30.0	1250.0	31.8
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	31.0
20.0	37.4	2500.0	31.8
25.0	44.9	3150.0	30.0
31.5	47.1	4000.0	30.0
40.0	44.0	5000.0	30.0
50.0	45.0	6300.0	30.0
63.0	44.8	8000.0	30.0
80.0	51.5	10000.0	30.0
100.0	68.3	12500.0	30.0
125.0	47.3	16000.0	30.0
160.0	42.9	20000.0	30.0
A-bew.	52.5		
Linear	69.1		

Anlage 18



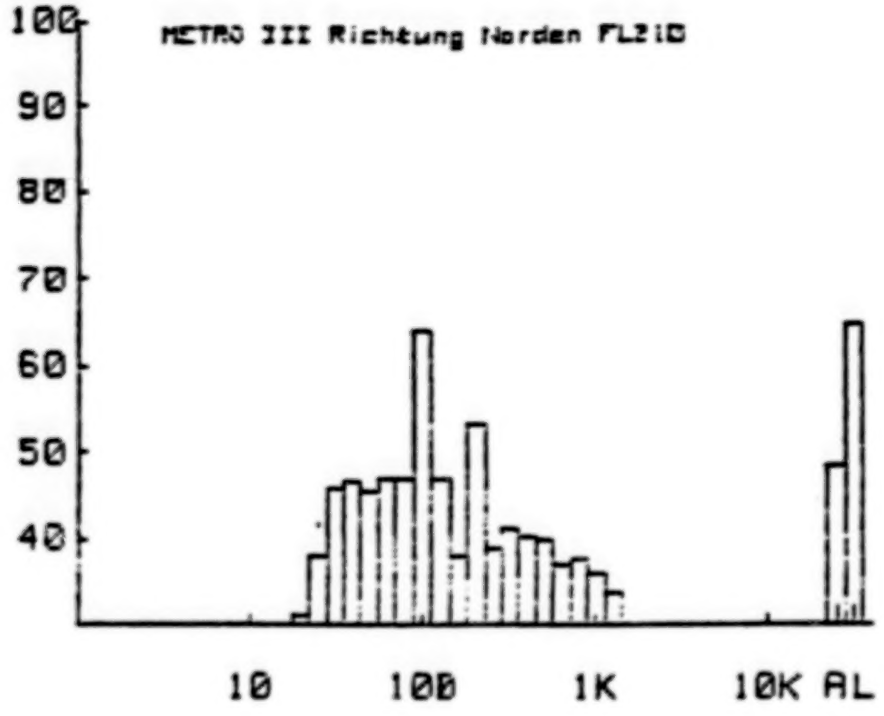
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	51.4
2.0	30.0	250.0	39.0
2.5	30.0	315.0	40.4
3.2	30.0	400.0	45.1
4.0	30.0	500.0	46.3
5.0	30.0	630.0	42.6
6.3	30.0	800.0	38.4
8.0	30.0	1000.0	33.5
10.0	30.0	1250.0	31.0
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	30.0
20.0	33.5	2500.0	31.0
25.0	43.0	3150.0	30.0
31.5	44.7	4000.0	30.0
40.0	43.1	5000.0	30.0
50.0	46.8	6300.0	30.0
63.0	46.2	8000.0	30.0
80.0	46.9	10000.0	30.0
100.0	64.9	12500.0	30.0
125.0	48.7	16000.0	30.0
160.0	37.8	20000.0	30.0
A-bew.	49.8		
Linear	64.9		

Anlage 19



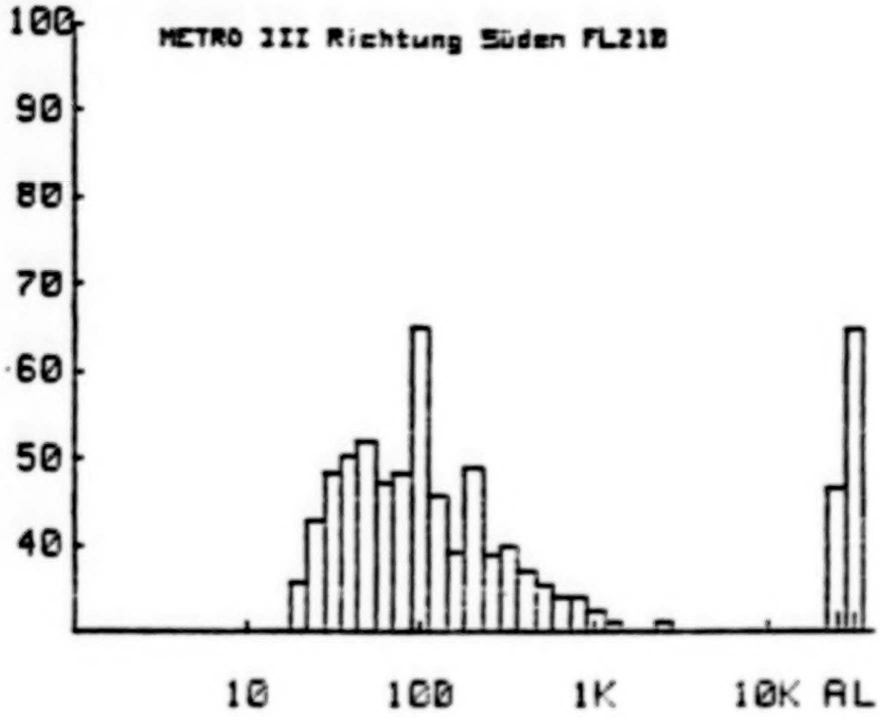
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	50.9
2.0	30.0	250.0	40.5
2.5	30.0	315.0	40.6
3.2	30.0	400.0	36.0
4.0	30.0	500.0	35.4
5.0	30.0	630.0	34.4
6.3	30.0	800.0	34.8
8.0	30.0	1000.0	32.4
10.0	30.0	1250.0	31.0
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	30.0
20.0	33.0	2500.0	30.0
25.0	39.1	3150.0	30.0
31.5	47.4	4000.0	30.0
40.0	41.7	5000.0	30.0
50.0	41.2	6300.0	30.0
63.0	46.6	8000.0	30.0
80.0	48.1	10000.0	30.0
100.0	66.4	12500.0	30.0
125.0	48.1	16000.0	30.0
160.0	38.4	20000.0	30.0
A-bew.	50.1		
Linear	68.0		

Anlage 20



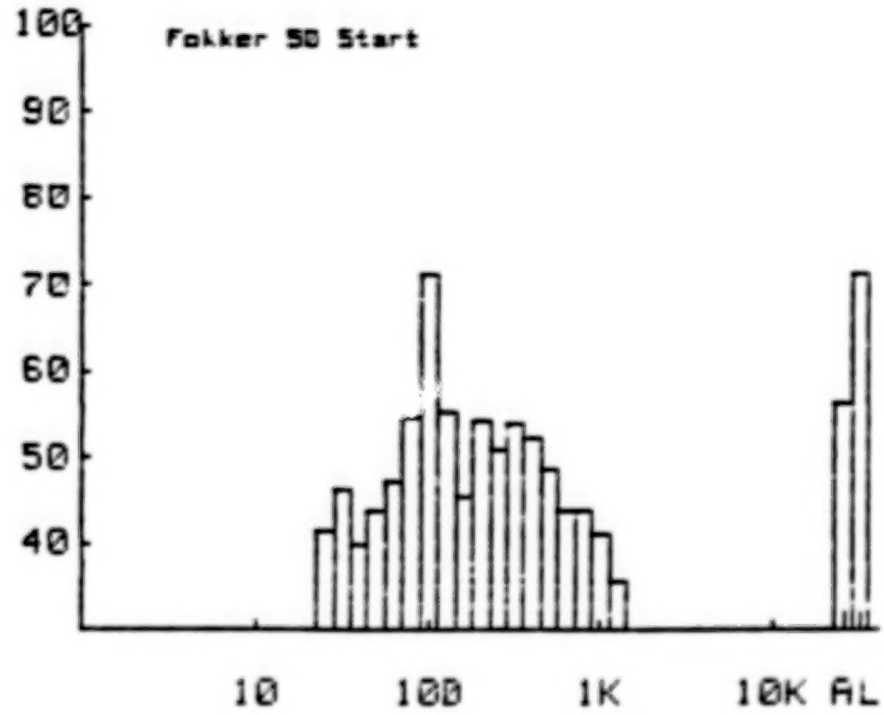
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	53.4
2.0	30.0	250.0	39.1
2.5	30.0	315.0	41.4
3.2	30.0	400.0	40.4
4.0	30.0	500.0	40.1
5.0	30.0	630.0	37.0
6.3	30.0	800.0	37.8
8.0	30.0	1000.0	36.3
10.0	30.0	1250.0	33.5
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	30.0
20.0	31.0	2500.0	30.0
25.0	38.1	3150.0	30.0
31.5	45.7	4000.0	30.0
40.0	46.6	5000.0	30.0
50.0	45.5	6300.0	30.0
63.0	46.8	8000.0	30.0
80.0	46.8	10000.0	30.0
100.0	64.0	12500.0	30.0
125.0	47.0	16000.0	30.0
160.0	38.1	20000.0	30.0
A-bew.	48.6		
Linear	64.6		

Anlage 21



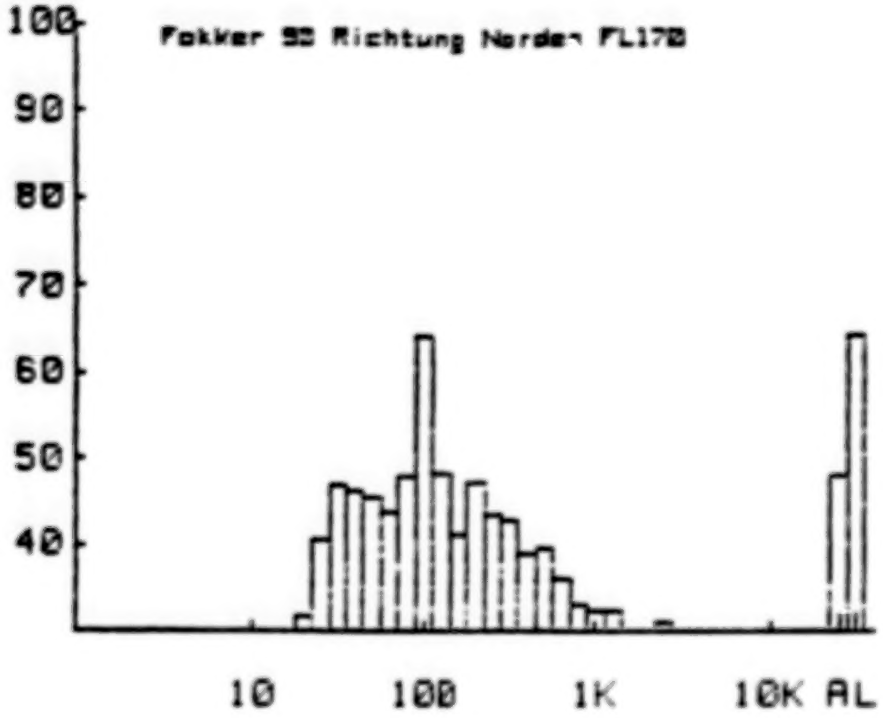
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	49.1
2.0	30.0	250.0	38.9
2.5	30.0	315.0	40.0
3.2	30.0	400.0	37.0
4.0	30.0	500.0	35.1
5.0	30.0	630.0	34.0
6.3	30.0	800.0	34.0
8.0	30.0	1000.0	32.4
10.0	30.0	1250.0	31.0
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	30.0
20.0	35.7	2500.0	31.0
25.0	42.7	3150.0	30.0
31.5	48.6	4000.0	30.0
40.0	50.4	5000.0	30.0
50.0	52.0	6300.0	30.0
63.0	47.2	8000.0	30.0
80.0	48.5	10000.0	30.0
100.0	65.0	12500.0	30.0
125.0	45.7	16000.0	30.0
160.0	39.3	20000.0	30.0
A-bew.	46.7		
Linear	64.8		

Anlage 22



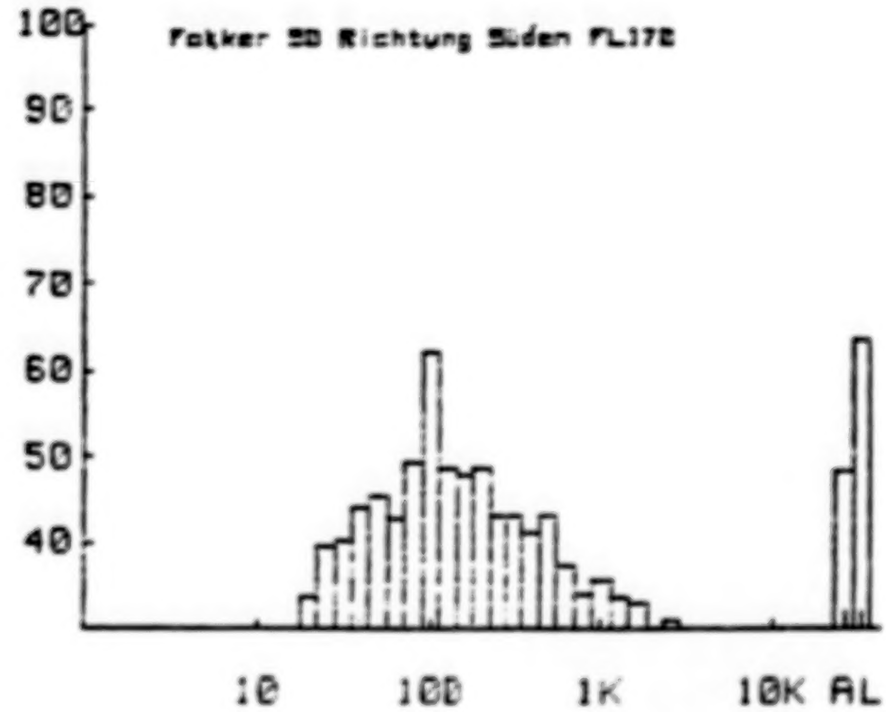
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	54.3
2.0	30.0	250.0	51.1
2.5	30.0	315.0	53.9
3.2	30.0	400.0	52.3
4.0	30.0	500.0	48.7
5.0	30.0	630.0	43.9
6.3	30.0	800.0	43.8
8.0	30.0	1000.0	41.3
10.0	30.0	1250.0	36.0
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	30.0
20.0	30.0	2500.0	30.0
25.0	41.7	3150.0	30.0
31.5	46.4	4000.0	30.0
40.0	39.9	5000.0	30.0
50.0	43.9	6300.0	30.0
63.0	47.4	8000.0	30.0
80.0	54.4	10000.0	30.0
100.0	70.9	12500.0	30.0
125.0	55.1	16000.0	30.0
160.0	45.4	20000.0	30.0
A-bew.	56.1		
Linear	71.1		

Anlage 23



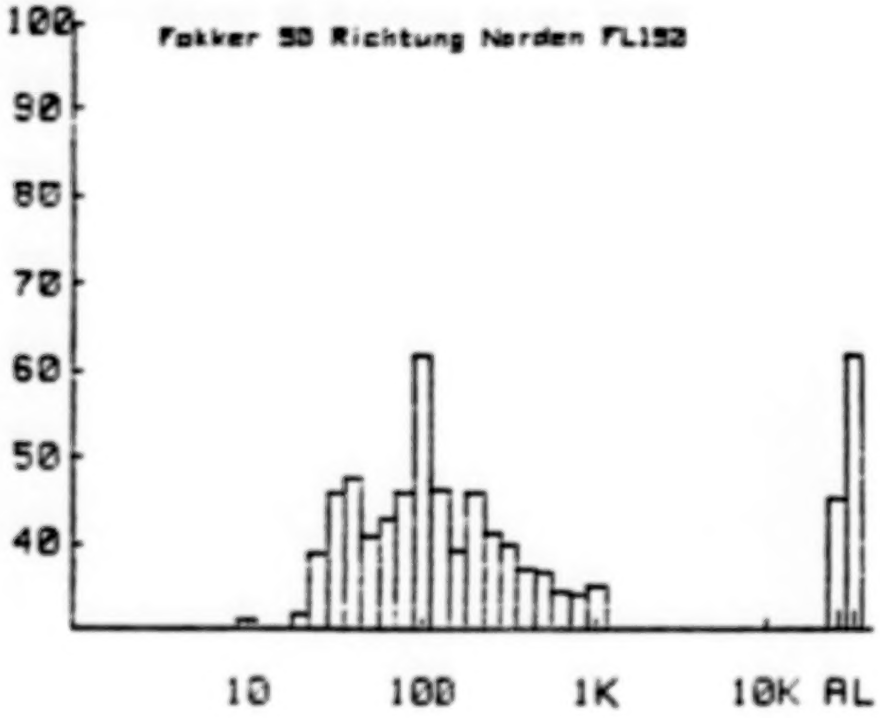
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	47.4
2.0	30.0	250.0	43.5
2.5	30.0	315.0	42.7
3.2	30.0	400.0	38.9
4.0	30.0	500.0	39.7
5.0	30.0	630.0	36.3
6.3	30.0	800.0	33.0
8.0	30.0	1000.0	32.4
10.0	30.0	1250.0	32.4
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	30.0
20.0	31.0	2500.0	31.0
25.0	40.6	3150.0	30.0
31.5	46.8	4000.0	30.0
40.0	46.2	5000.0	30.0
50.0	45.3	6300.0	30.0
63.0	43.7	8000.0	30.0
80.0	47.9	10000.0	30.0
100.0	64.2	12500.0	30.0
125.0	48.1	16000.0	30.0
160.0	41.4	20000.0	30.0
A-bew.	47.9		
Linear	63.9		

Anlage 24



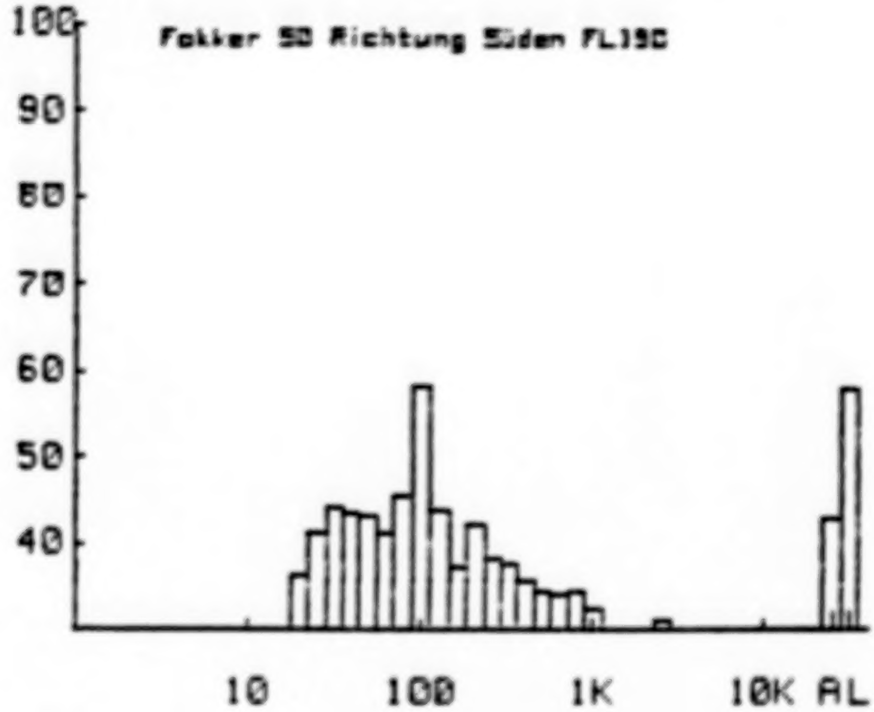
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	48.9
2.0	30.0	250.0	43.2
2.5	30.0	315.0	43.0
3.2	30.0	400.0	41.2
4.0	30.0	500.0	43.3
5.0	30.0	630.0	37.6
6.3	30.0	800.0	34.0
8.0	30.0	1000.0	35.7
10.0	30.0	1250.0	33.5
12.5	30.0	1600.0	33.0
16.0	30.0	2000.0	30.0
20.0	33.5	2500.0	31.0
25.0	39.7	3150.0	30.0
31.5	40.3	4000.0	30.0
40.0	44.2	5000.0	30.0
50.0	45.4	6300.0	30.0
63.0	42.9	8000.0	30.0
80.0	49.4	10000.0	30.0
100.0	62.0	12500.0	30.0
125.0	49.0	16000.0	30.0
160.0	48.0	20000.0	30.0
A-bew.	48.3		
Linear	63.5		

Anlage 25



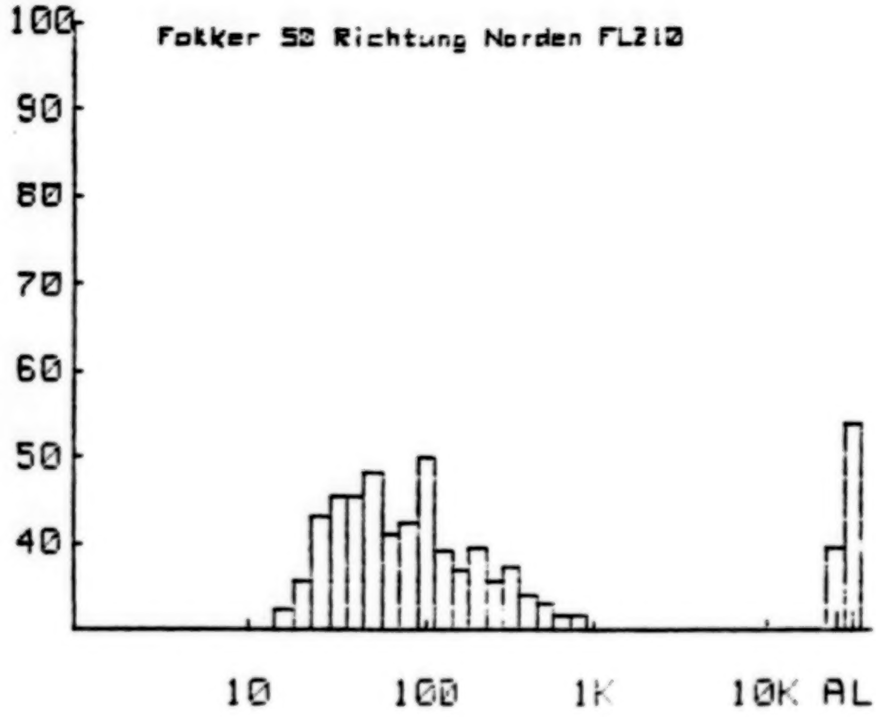
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	45.9
2.0	30.0	250.0	41.1
2.5	30.0	315.0	40.1
3.2	30.0	400.0	37.2
4.0	30.0	500.0	36.7
5.0	30.0	630.0	34.4
6.3	30.0	800.0	34.0
8.0	30.0	1000.0	34.8
10.0	31.0	1250.0	30.0
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	30.0
20.0	31.6	2500.0	30.0
25.0	38.9	3150.0	30.0
31.5	45.6	4000.0	30.0
40.0	47.5	5000.0	30.0
50.0	41.0	6300.0	30.0
63.0	42.7	8000.0	30.0
80.0	45.9	10000.0	30.0
100.0	61.9	12500.0	30.0
125.0	46.2	16000.0	30.0
160.0	39.4	20000.0	30.0
A-bew.	45.1		
Linear	61.8		

Anlage 26



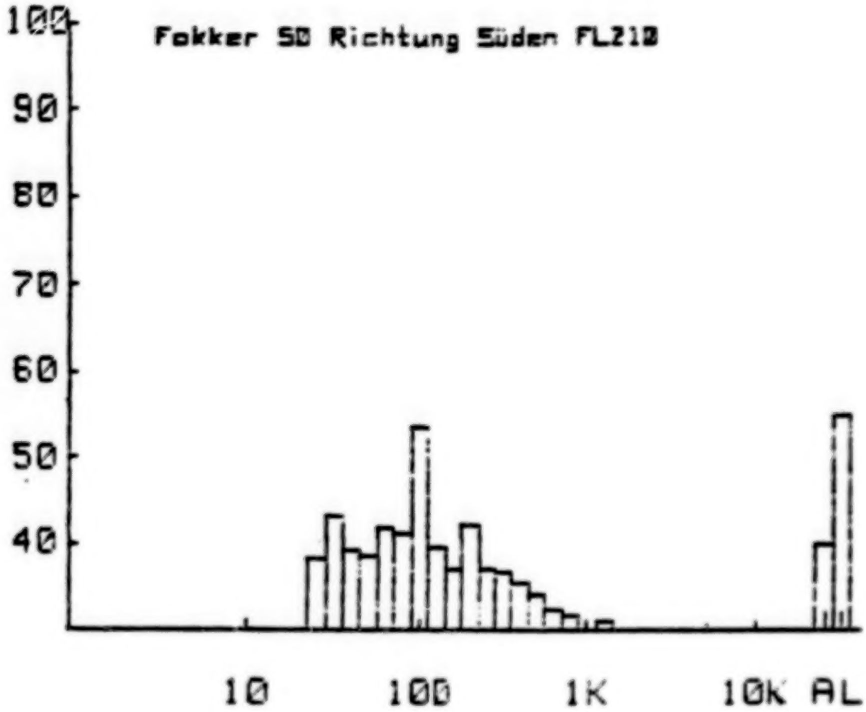
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	42.1
2.0	30.0	250.0	38.4
2.5	30.0	315.0	37.8
3.2	30.0	400.0	35.7
4.0	30.0	500.0	34.4
5.0	30.0	630.0	34.0
6.3	30.0	800.0	34.4
8.0	30.0	1000.0	32.4
10.0	30.0	1250.0	30.0
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	30.0
20.0	36.5	2500.0	31.0
25.0	41.4	3150.0	30.0
31.5	44.1	4000.0	30.0
40.0	43.6	5000.0	30.0
50.0	43.1	6300.0	30.0
63.0	41.2	8000.0	30.0
80.0	45.3	10000.0	30.0
100.0	57.9	12500.0	30.0
125.0	43.9	16000.0	30.0
160.0	37.6	20000.0	30.0
A-bew	42.9		
Linear	57.8		

Anlage 27



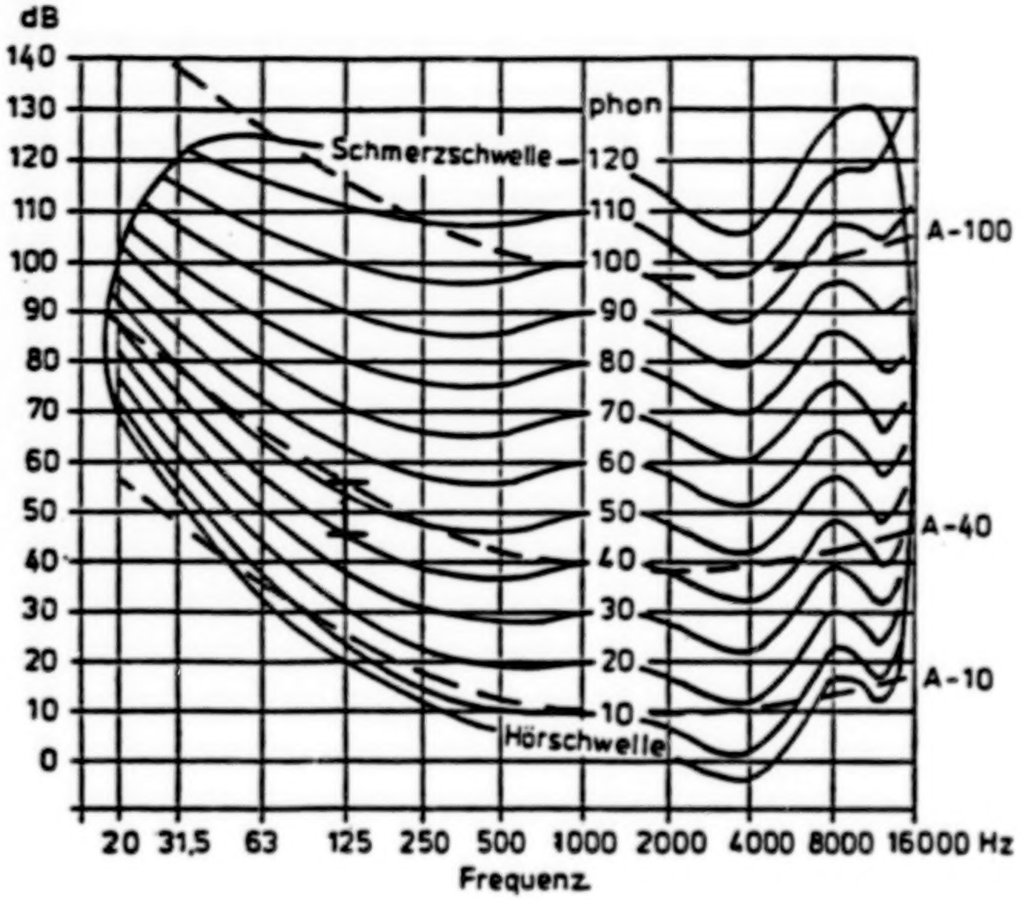
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	39.7
2.0	30.0	250.0	35.7
2.5	30.0	315.0	37.4
3.2	30.0	400.0	34.0
4.0	30.0	500.0	33.0
5.0	30.0	630.0	31.8
6.3	30.0	800.0	31.8
8.0	30.0	1000.0	30.0
10.0	30.0	1250.0	30.0
12.5	30.0	1600.0	30.0
16.0	32.4	2000.0	30.0
20.0	35.7	2500.0	30.0
25.0	43.0	3150.0	30.0
31.5	45.4	4000.0	30.0
40.0	45.3	5000.0	30.0
50.0	48.3	6300.0	30.0
63.0	41.1	8000.0	30.0
80.0	42.4	10000.0	30.0
100.0	50.1	12500.0	30.0
125.0	39.5	16000.0	30.0
160.0	37.2	20000.0	30.0
A-bew.	39.6		
Linear	54.0		

Anlage 28



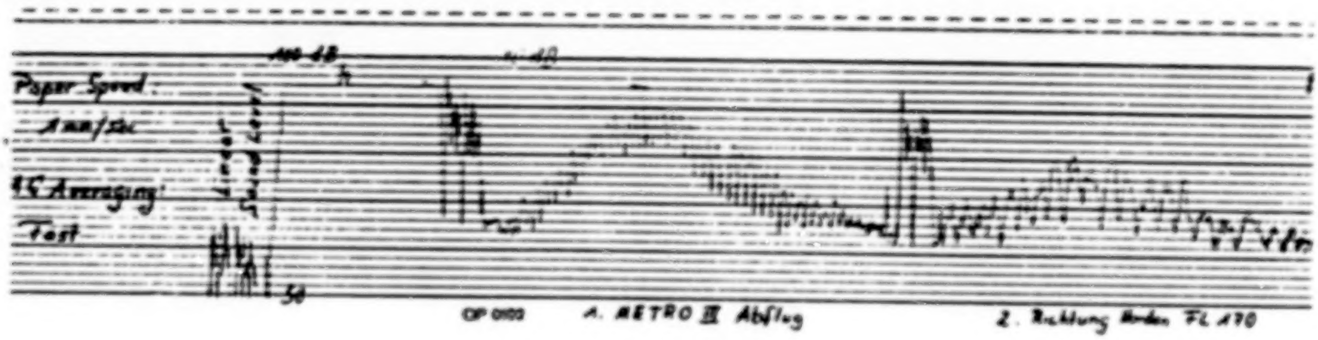
f[Hz]	L[dB]	f[Hz]	L[dB]
1.6	30.0	200.0	42.1
2.0	30.0	250.0	37.2
2.5	30.0	315.0	36.7
3.2	30.0	400.0	35.1
4.0	30.0	500.0	34.0
5.0	30.0	630.0	32.4
6.3	30.0	800.0	31.8
8.0	30.0	1000.0	30.0
10.0	30.0	1250.0	31.0
12.5	30.0	1600.0	30.0
16.0	30.0	2000.0	30.0
20.0	30.0	2500.0	30.0
25.0	38.4	3150.0	30.0
31.5	43.1	4000.0	30.0
40.0	39.5	5000.0	30.0
50.0	38.7	6300.0	30.0
63.0	41.9	8000.0	30.0
80.0	41.4	10000.0	30.0
100.0	53.6	12500.0	30.0
125.0	39.7	16000.0	30.0
160.0	37.0	20000.0	30.0
A-bew.	40.0		
Linear	55.0		

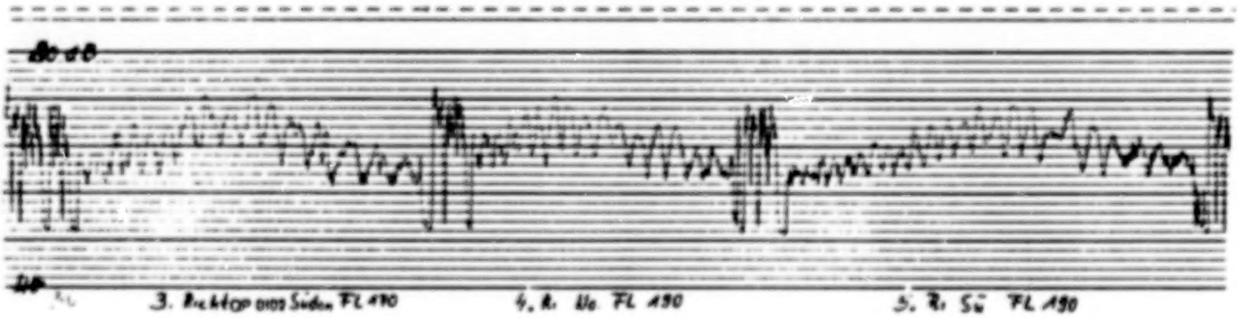
Anlage 29

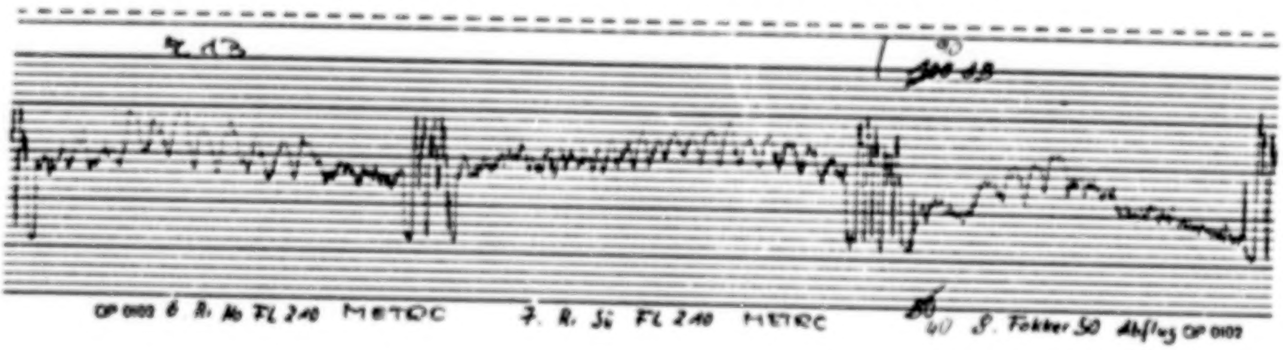


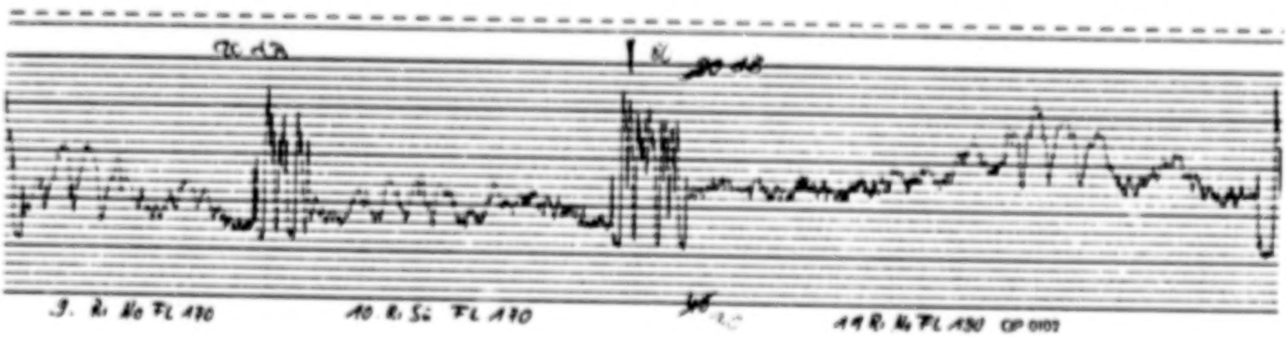
Kurven gleicher Lautstärke und festgelegter Verlauf der A-Bewertung

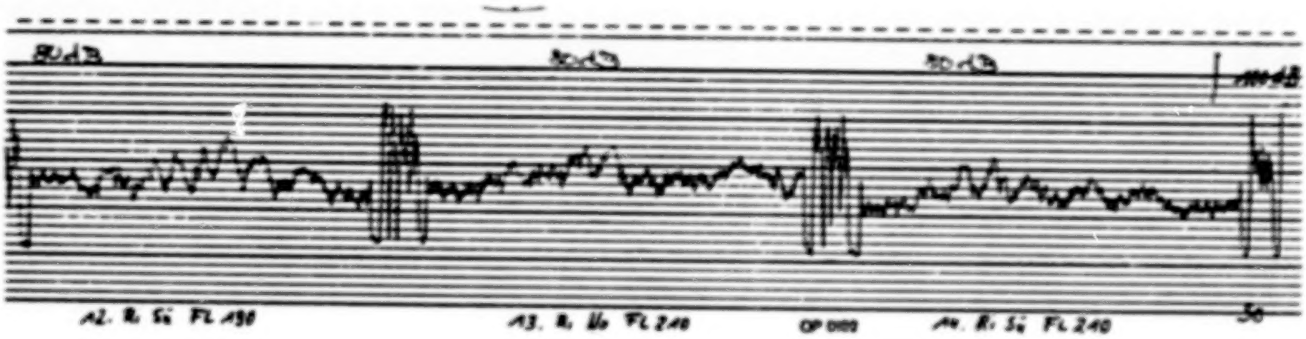
Anlage 30


Paper Speed:
1 mm/sec
15 Averaging:
Fast
100 dB
50
CP 0102
1. METRO III Abflug
2. Richtung Norden FL 170


80 dB
3. Richt CP 0102 Süden FL 170
4. R. No FL 190
5. R. Sü FL 190


CP 0102 6 R. No FL 240 METOC
7. R. Sü FL 240
8. Fokker 50 Abflug CP 0102


90 dB
9. R. No FL 170
10. R. Sü FL 170
11 R. No FL 190 CP 0102



SOUND PROPAGATION ELEMENTS IN EVALUATION OF EN ROUTE NOISE OF ADVANCED TURBOFAN AIRCRAFT

Louis C. Sutherland

Wyle Laboratories
128 Maryland St.
El Segundo, California

John Wesler

Wyle Laboratories
2001 Jefferson Davis Hwy, Suite 701
Arlington, Virginia

INTRODUCTION

Cruise noise from an advanced turboprop aircraft is reviewed on the basis of available wind tunnel data to estimate the aircraft noise signature at the source. Available analytical models are used to evaluate the sound levels at the ground. The analysis allows reasonable estimates to be made of the community noise levels that might be generated during cruise by such aircraft, provides the basis for preliminary comparisons with available data on noise of existing aircraft during climb and helps to identify the dominant elements of the sound propagation models applicable to this situation.

ATP NOISE CHARACTERISTICS

Experimental data obtained by NASA (Dittmar, NASA-TM-87302) on a scale model eight-blade UDF turboprop configuration were used as the starting point of the analysis. The model consisted of dual eight-blade contra-rotating propellers that were tested at cruise speeds in a wind tunnel. Figure 1 summarizes the noise levels measured at a radius of 0.3 blade diameters for the first six blade harmonics as a function of angle in a horizontal plane relative to the inflow direction. For purposes of this analysis, semi-empirical directivity and spectrum shape models were developed to describe the data. Figure 2 shows the generalized directivity model which indicated that a single directivity curve fit the data quite well for the first five harmonics. The empirical curve also compares reasonably with the theoretical trend expected for the directivity of an eight-blade propeller. Figure 3 shows that a simple model could also be used to define the relative level of each of the harmonics. Also shown are data from Dittmar on an ATP model which show a similar trend in spectrum shape. Based on these empirical models, it was thus possible to estimate the level and directivity at the source of cruise noise from a UDF aircraft. Since the directivity was assumed to be axisymmetric, the model could be used to estimate, to a first approximation, the time history of sound levels on the ground directly under the aircraft or to the side, given a reasonable sound propagation model.

SOUND PROPAGATION MODEL

The basic assumptions made to define the sound propagation model can be summarized as follows:

- At a cruise altitude of 30,000 feet, the acoustic impedance of air is equal to 0.385 times the value at sea level, and this is expected to decrease the sound power radiated by the dipole propeller noise sources by

$$\Delta L_W = 20 \text{ Log } (0.385) = -8.2 \text{ dB}$$

- This decrease in sound power output is partially compensated for by an increase in sound pressure level of one-half this amount. By conservation of energy, for the same sound intensity at 10 km and at the ground, the increase in acoustic impedance at the ground by a factor of 1/0.385 will cause the mean square sound pressure to increase by the same amount, so the sound pressure level will increase by 10 Log (1/0.385) = 4.1 dB. Combined with the above decrease in power level, this results in a net decrease in sound level of 4.1 dB due to the change in acoustic impedance.

- If this change in acoustic impedance happened abruptly, there would be a decrease in sound transmission due to the reflection at an impedance mismatch interface. However, finite difference calculations indicate that there should not be any such transmission loss since the acoustic impedance changes so little over a distance comparable to a wavelength as the sound travels from 10 km to the ground.

- Propagation loss due to atmospheric absorption is estimated according to a forthcoming proposed revision to the American National Standard ANSI S1.26 method for computing atmospheric absorption losses. The currently accepted industry standard method for

computing this loss for aircraft noise, SAE ARP 866A, is not at all usable in its present form for this computation since it does not account for any change in atmospheric pressure nor is it capable of accommodating the extremely wide range of humidity content involved.

- Refraction of the sound emanating from the source is estimated on the basis of simple ray theory assuming a standard linear (lapse rate) temperature gradient of -0.0065 C/meter superimposed on a linear wind speed gradient which was varied from -0.001 1/s to -0.004 1/s.

- Propagation loss due to spherical spreading will be 46 dB between a reference distance of 50 meters from the source and a propagation distance of 10 km.

The predicted cumulative air absorption loss at a (full scale) blade passage fundamental frequency of 250 Hz is shown in Figure 4 as a function of source altitude for a nominal "standard" atmosphere. This uses the 1964 ICOA standard for temperature and pressure and available data on humidity at altitude (USAF Handbook of Geophysics and Space Environments, 1965). Also shown in Figure 4 are predicted values of the air absorption loss based on actual profiles provided by FAA of temperature, pressure and humidity measured at several locations in the U.S. The latter data indicate the "standard" air absorption loss curve in Figure 4 may be conservative. Note also that the greatest rate of increase in the cumulative air absorption loss, which reaches a maximum of 8 to 14 dB at 10 km at 250 Hz, occurs at around 6 to 7 km. The total cumulative air absorption loss for the "standard" atmospheric profile over a 10 km path that was used for Figure 4 is shown in Figure 5 as a function of frequency. Based on pANSI 1.26, the total absorption A(f) to 10 km at frequencies from 50 to 10,000 KHz is very well described by a simple third-order polynomial expression:

$$A(f) = 10^{[3.203 + 3.221X - 0.9552X^2 + 0.14X^3]}, \quad dB$$

where $X = Lg(f)$ and f is in Hz.

The effect of refraction of the nonuniform atmosphere is illustrated in Figure 6 by calculated sound ray paths for various initial ray angles below the horizontal for a source at an elevation of 10 km on a nominal "standard" day with the temperature gradient identified earlier and a wind speed gradient of -0.002 1/s and for ±50 percent variation in that gradient. The key point here is that only a limited portion of the sound radiated by the source (i.e., ray angles greater than the limiting angle of 35°) would reach the ground, and that small changes in the combined temperature and wind gradient would be expected to cause large variations in the received sound levels on the ground at positions near the point where the "limiting" ray strikes the ground.

It is important to point out, of course, that this simplified sound propagation model makes no attempt to evaluate the fluctuations in sound level that can occur for UDF or ATP noise due to interference effects of multipath transmission and turbulence scattering effects on the blade passage tones in a real atmosphere. However, it should provide a reasonable basis for estimates of the average time history of the noise signature on the ground.

ESTIMATED CRUISE NOISE LEVELS ON THE GROUND

Applying the preceding models, such estimates were made of the time history of sound levels on the ground for the blade passage frequency components of UDF (or ATP) noise. Figure 7 is a typical example of such an estimate for a BPF of 200 Hz. The figure shows the estimated time history for an observer directly under the aircraft flight path and for an observer 10 km and 20 km to the side of the flight track. Note that the sound exposure level, the time integrated measure of noise exposure, drops off very slowly with sideline distance so that the noise carpet created by cruise of UDF/ATP aircraft may be considerably wider than for current turbofan aircraft in cruise or in a climbing mode. Data on the latter are compared in Figure 8 with the estimated range of en route cruise noise levels from UDF/ATP aircraft.

While the estimated levels are, indeed, comparable to those of current aircraft during climb, extrapolation of the latter to levels at en route cruise altitude comparable to that for the UDF/ATP aircraft shows that the noise levels on the ground for the UDF/ATP aircraft would be appreciably higher than en route cruise noise levels of current turbofan aircraft.

SUMMARY

Acoustic measurements of UDF/ATP models in wind tunnel tests can provide a basis for estimating source levels for full size aircraft.

A simplified sound propagation model shows that

- The difference in acoustic impedance between the ground and 10 km is expected to result in a net decrease in sound pressure level of about 4 dB relative to the level for the same source on the ground, ignoring all other effects.
- Cumulative air absorption losses at typical BPF around 200 Hz will amount to about 8 to 14 dB with the greatest losses at 6 to 7 km.
- Refraction effects will limit the sound exposure on the ground to sound rays emanating at angles greater than about 35° below the horizontal.
- Variation in mean temperature and wind profiles may cause large variations in average sideline noise levels.
- En route cruise noise levels of UDF/ATP aircraft will be comparable to those of existing jet aircraft during climb but are likely to exceed appreciably cruise noise levels of existing aircraft.

MEASURED HARMONIC LEVELS FOR MODEL UDF

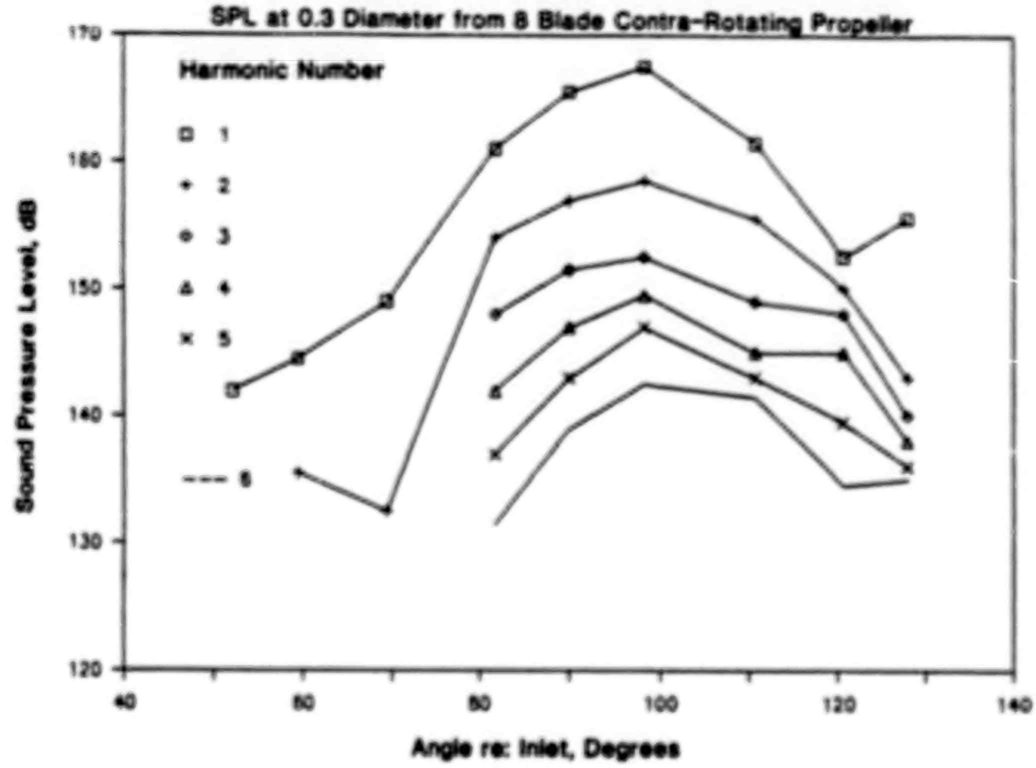


Figure 1.

RELATIVE HARMONIC LEVELS FOR UDF

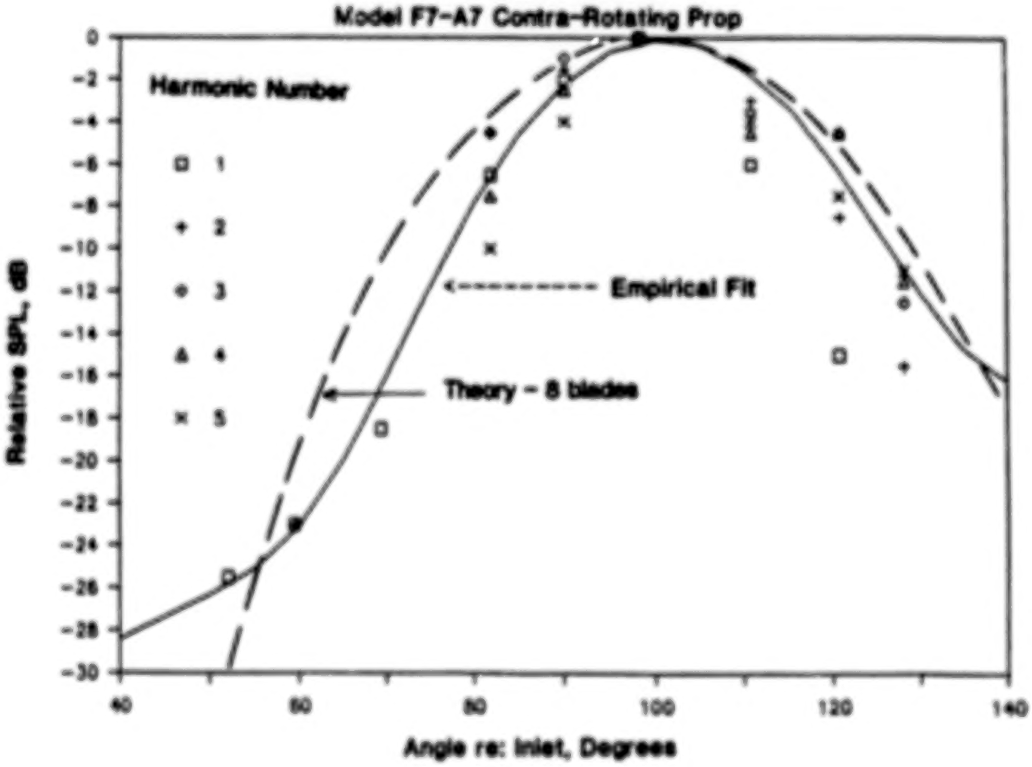


Figure 2.

RELATIVE SPECTRUM FOR 8 BLADE ATP/UDF

DATA FROM DITTMAR, NASA TM 87302

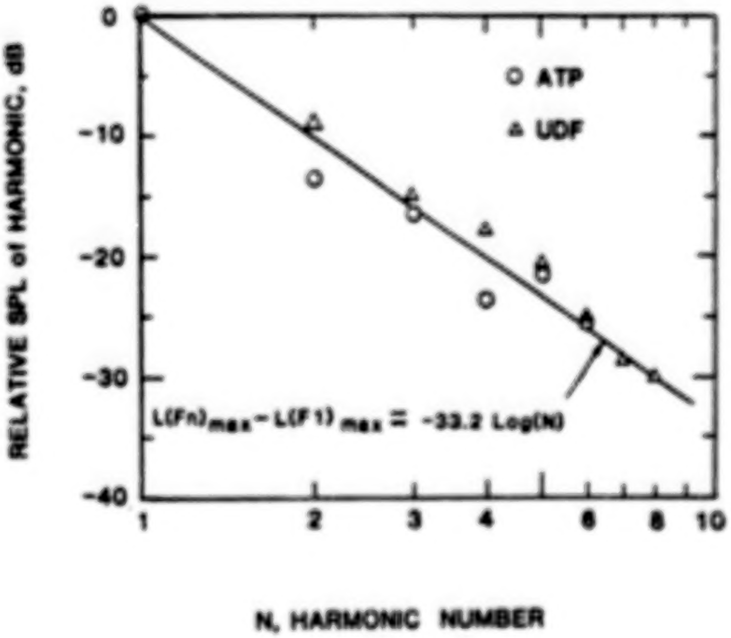


Figure 3.

CUMULATIVE AIR ABSORPTION LOSS at 250 Hz
VERSUS SOURCE ALTITUDE

Mean Annual Conditions at 6 Locations Compared to "Standard" Atmosphere in pANSI S1.26

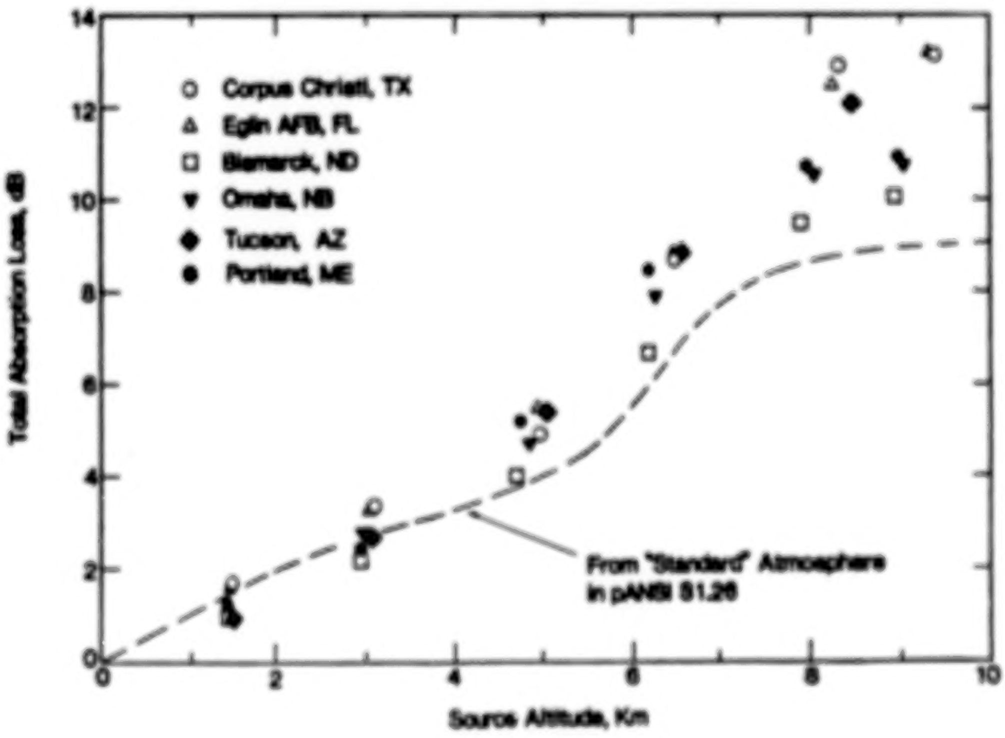


Figure 4.

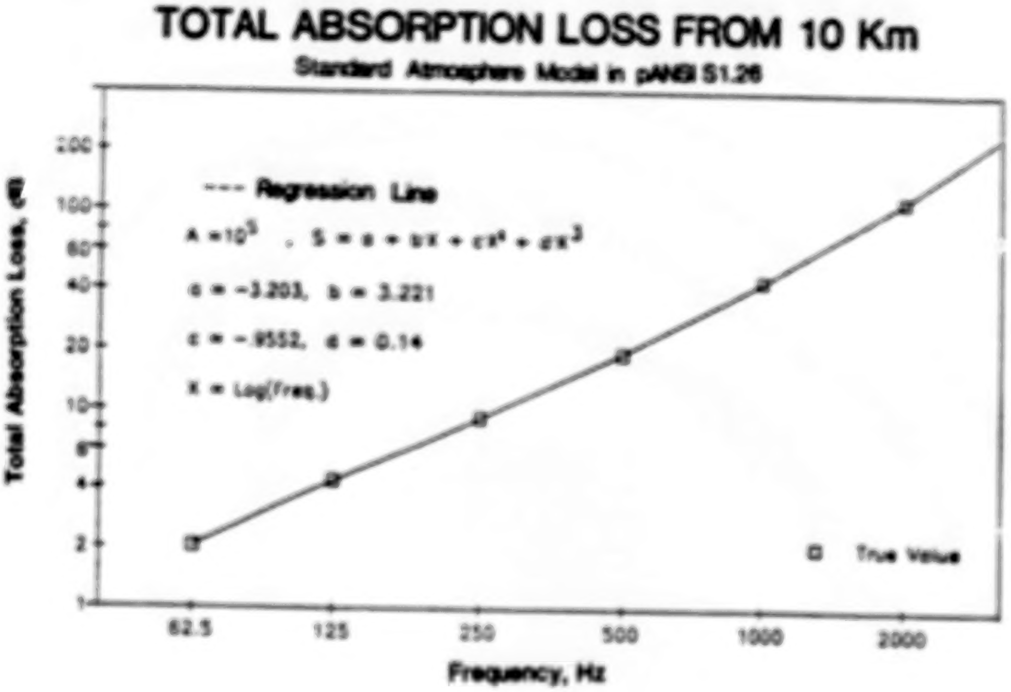


Figure 5.

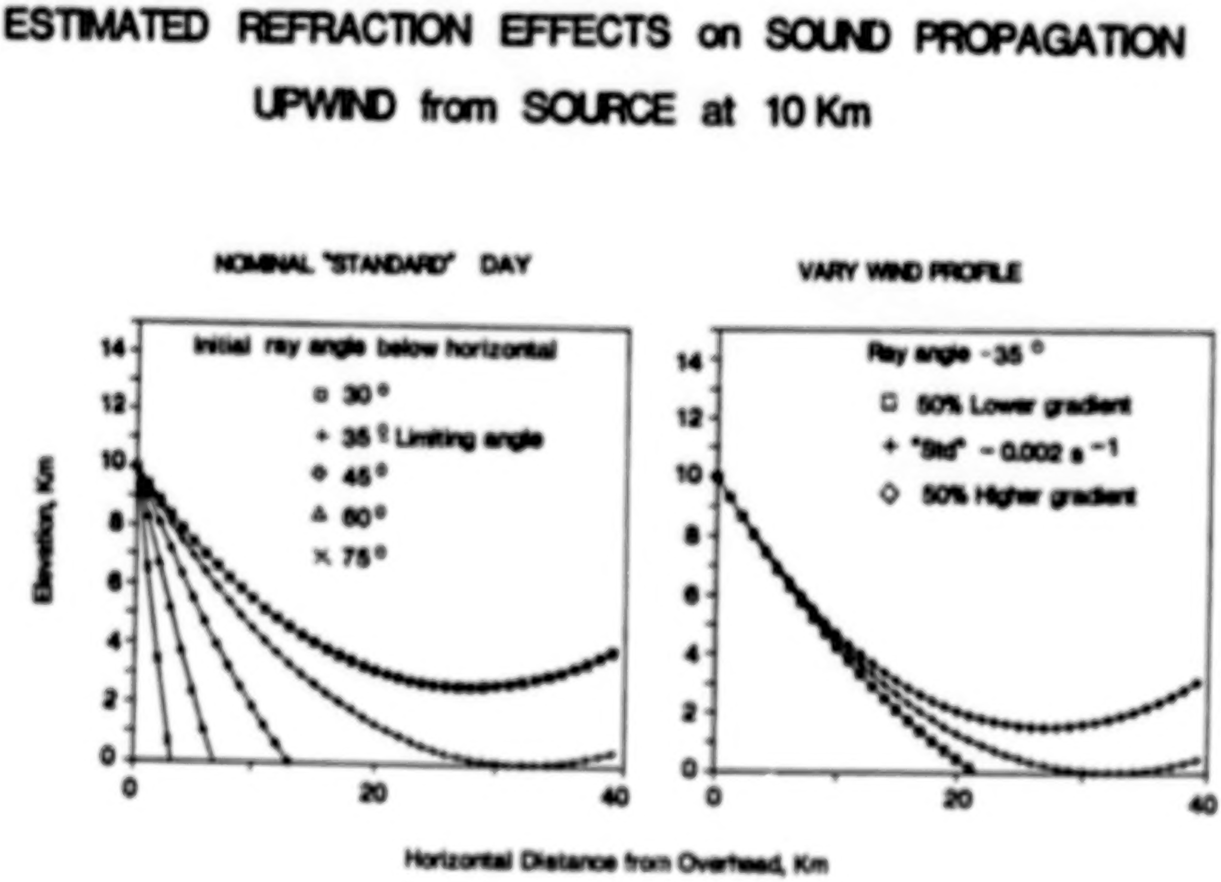


Figure 6.

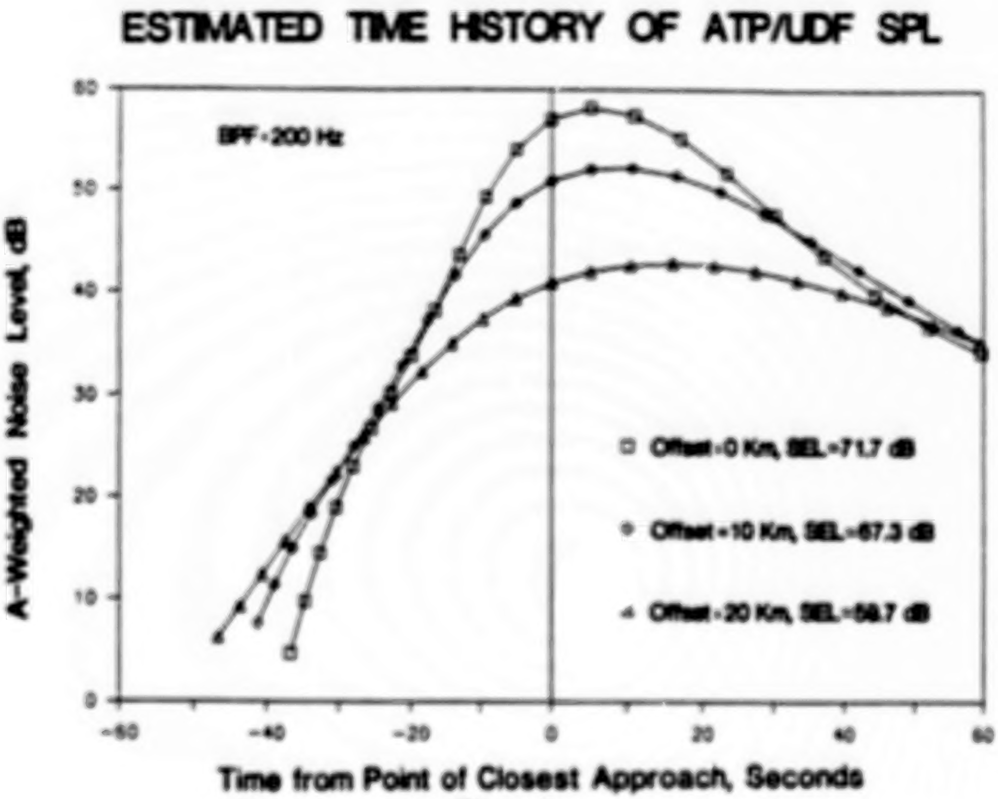


Figure 7.

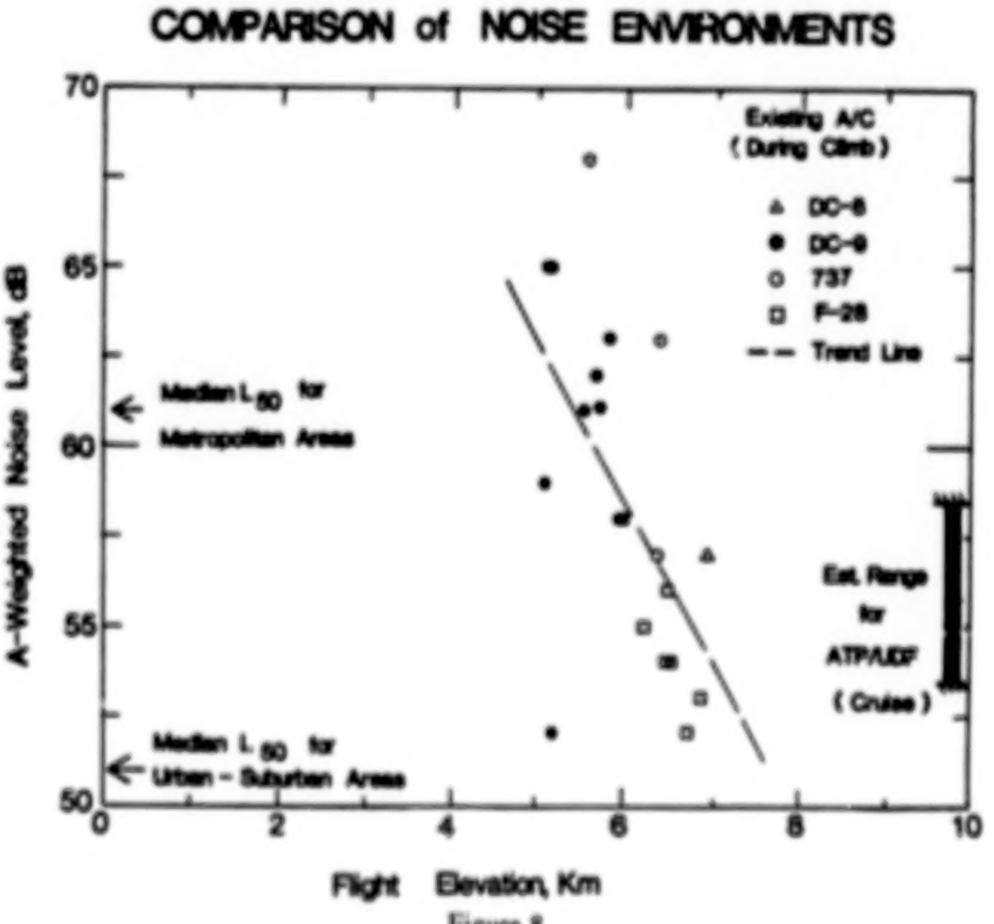


Figure 8.

PRELIMINARY THOUGHTS ON AN ACOUSTIC METRIC FOR THE WILDERNESS AIRCRAFT OVERFLIGHT STUDY

Robin T. Harrison
Program Leader, Aviation
U.S.D.A. Forest Service
Technology & Development Center, San Dimas, CA

Lawrence H. Hartmann
Research Social Scientist
U.S.D.A. Forest Service
Intermountain Research Station, Missoula, MT

This paper (erroneously referenced as ref. 1 in its companion paper, U.S. Forest Service and National Park Service Wilderness Aircraft Overflight Study: Sociological Background and Study Plan) presents some preliminary thoughts on acoustic metrics which may be appropriate for the measurement of sound caused by aircraft overflights of wilderness areas. The reader may wish to consult the companion paper for general background and a discussion of some of the human issues regarding aircraft impact on the dispersed wildland recreationist.

It could be argued that, by definition, wilderness areas contain very few people and thus the aggregate impact on populations using the wilderness is small. However, wilderness is very important to a large number of people, and "wilderness experience" has proven to be a very precious commodity. Our agencies, the National Park Service and the U.S. Forest Service are mandated by law to manage wilderness to the best of our ability, and to maintain the unspoiled character of this significant land area.

Differences between the wilderness situation and the much better studied airport-community situation include the very low background sound that exists in wilderness areas. Measurements of L_{50} = 20 dBA in desert and sparsely wooded areas, and 30-40 dBA in coniferous forests, are representative. Further, background sounds are highly variable as a function of time, wind, and the presence of water.

Limited, informal studies by your authors have shown that the dominant background sound for most users of wilderness areas, at least in terms of amplitude, is self-generated noise. Conversation, brushing through vegetation, footfalls, etc., are by far the loudest sounds encountered by most wilderness visitors.

Another variation between the community noise and the wilderness noise situation is that, in wilderness, populations are transient. Hartmann, (see companion paper for citations) has documented the average wilderness stay to be somewhat less than a day. This contrasts sharply with the community noise situation.

Finally, alluded to above, is the statutory scheme. Wilderness areas are declared and established by Congress, with somewhat arbitrary boundaries, to be land where lasting signs of man are excluded, or at least minimized.

As mentioned above, a dose response relationship is sought. How to characterize this dose is the task at hand.

At first thought, the parameter detectability, d' would seem to be the obvious candidate; d' is really the measure of an energy flattened signal plus noise to noise ratio, in third octave bands, corrected for the efficiency of the observer. For a

discussion of the technical aspects of d', see ref. 1. One reason to recommend d' is that it considers the background. (We assume that impact on a human observer is a function of the background sound as well as the intruding sound.) This metric is currently used by land managers to site recreation facilities. The methodology proposed by the Forest Service (see ref. 9 of the companion paper) assumes that for areas which present the most primitive recreation opportunities, a very low d' is appropriate. As the recreation opportunity becomes less "wilderness", a higher d', that is, a greater "intrusion", is acceptable. This method has only anecdotal support; it has been successfully used in a number of locations, as reported by the managers of those locations. No systematic study of its efficacy has been published to the authors' knowledge.

The use of d' is not without its problems. Perhaps the greatest of these is that the current state of the art provides no "d' meter". The only way to determine d' is to tape record intrusive sounds and background sounds on an instrumentation tape recorder, return them to the laboratory, and using a rather sophisticated computerized frequency analysis and computational scheme, develop d's in a number of slices of time. Since it is impossible to separate the signal from the noise, d' can be calculated only retrospectively. Further, the definition of d' includes an observer efficiency, and this observer efficiency has been shown to depend strongly on *a priori* information that the listener possesses and the risk associated with detection that the listener faces. For a further discussion of this point, see ref. 2.

As mentioned above, the literature does not contain controlled studies relating d' of various levels to various visitor responses. However, there is good data correlating d' with annoyance of low level sounds. (See ref. 3.)

A further disadvantage of the d' scheme is that the unit is not familiar to even knowledgeable professionals, much less the general public. The experience of the authors in explaining measurements made in decibels A to managers without strong technical backgrounds confirms this disadvantage.

The second metric which comes to mind is some variant of the "time above" scheme. Features which recommend such a metric are that it is very easy to understand, i.e., preliminary work (ref. 4) indicates that for approximately one-half the time, helicopter noise is "clearly audible" at Grand Canyon National Park. However, this assumes either a particular sound level, or a particular d', defines the threshold of audibility. As mentioned above, the observer efficiency in the d' definition is difficult to quantify and probably depends on many variables personal to the listener. There seems to be no sound level, either A weighted or linear, which defines audibility or a threshold of annoyance under outdoor conditions. So, the same problems which argue against the selection of d' for a metric argue against "time above" as a metric.

A third thought, perhaps called "back to basics", suggests itself. CNEL, or PNL, or L_{eq24} have served well in community noise measurements. Some modifications of these schemes, perhaps with extra penalties for a slow or very fast onset rate, or longer than "average" durations, could correlate with impact as well as more sophisticated measures. In their favor, such methods are widely recognized and well accepted. The negatives are obvious in that they do not consider background. Further, there is no support in the literature that we have found for the hypothesized corrections under wilderness or national park conditions.

The issue of onset rate deserves further discussion. Anecdotal information indicates that startle, particularly to pack stock, has caused some safety problems under some park and forest conditions. This is the type of onset that is found under military training routes, where high speed, low altitude tactical aircraft are flying.

On the other hand, very slow onset rates, such as observed with tour helicopters in the Grand Canyon, suggest to the listener the question, "When will it end?" The subjective impression of your authors is that the very long onset is as extra annoying as the startle.

Conclusion

We are faced with the following uncertainties:

1. Is the background as important in determining the impact of a given aircraft overflight sound as has been hypothesized? This is an issue which we consider crucial, and it will be studied early on in the program.

2. How can we decide which metric to use? Our current test plans call for continuous tape recording, with very high fidelity instrumentation, at-ear, ear level, and ground level sounds, including background and intrusion, for a broad assortment of different ecotypes; then, as many of the methods above as can economically be calculated will be.

3. This raises a third very interesting question, and that is, how does the visitor distinguish between aircraft noise and "wilderness noise"? In other words, is it possible to develop an aircraft detection algorithm? Certainly the human ear incorporates such an algorithm, and the authors' experience in wilderness areas substantiates that focused listening by a sophisticated human observer can detect aircraft acoustically at extremely low levels.

We speculate that background sound is poorly correlated across frequency as a function of time and also poorly correlated spatially. The overall levels change only slowly, but levels in each third octave band change rapidly and independently of each other. Aircraft sound, on the other hand, is well correlated across both

frequency and spatial domains. Using this knowledge, we believe it is possible to develop a small microprocessor-based package which will detect the presence of an aircraft acoustic signal. If this can be done, it can be combined with a package which can be worn by a hiker and will query him automatically when an aircraft is detected. This raises the intriguing possibility of an interactive system in which visitor response and visitor stimulus are measured simultaneously.

As mentioned above, our work in this largely uncharted area is just beginning. We earnestly solicit your ideas and criticism.

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2. BB & N Report 2202, Predicting Aural Detectability of Aircraft in Noise Backgrounds, by Fidell, Pearsons and Bennett, Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base, Ohio, July 1972.

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4. Dunholter, Paul H.; Mestre, Vincent E.; Harris, Roswell A.; Cohn, Louis F. 1989. Methodology for the Measurement and Analysis of Aircraft Sound Levels within National Parks. Final Report. Mestre Greve Associates Technical Report # 89-P07, Newport Beach, CA.

U.S. FOREST SERVICE AND NATIONAL PARK SERVICE WILDERNESS AIRCRAFT OVERFLIGHT STUDY: SOCIOLOGICAL BACKGROUND AND STUDY PLANS

Robin T. Harrison
Program Leader--Aviation
Technology & Development Center
San Dimas, California

Lawrence A. Hartmann
Research Social Scientist
Intermountain Research Station
Missoula, Montana

INTRODUCTION

This paper presents the background and sociological aspects of the combined U.S. Forest Service and National Park Service Wilderness Aircraft Overflight Study (WACOS). The paper presented at this conference by Harrison (ref. 1) discusses the acoustical considerations of the WACOS and is a companion piece to this paper. The WACOS broaches a new area of research by combining aspects of outdoor recreation sociology and aircraft noise response studies. The tasks faced by this study create new challenges and require innovative solutions.

Background information on the WACOS is presented in this paper, with special emphasis on sociological considerations related to the study. At the time of this writing, no data have yet been collected, so this paper will present background information, related issues, and plans for data collection. Some recent studies indicate that managers of Forest Service wildernesses and National Park Service areas consider aircraft overflights to be a problem to their users in some areas. Additional relevant background research from outdoor recreation sociology is discussed, followed by presentation of the authors' opinions of the most salient sociological issues faced by this study. The goals and desired end products are identified next, followed by a review of the methods anticipated to be used to obtain these results. Finally, a discussion and conclusion section is provided.

LITERATURE REVIEW

To some, the issue of aircraft flying over national parks and wildernesses may not seem worthy of substantial consideration. There are several indicators, however, that aircraft overflights are a major problem for the recreating public in at least some areas.

Many outdoor recreation studies have considered the demographic characteristics, activity patterns, travel patterns, motivations, conflicts, and even long-range projections of recreation use and users. While extensive research has been completed on the effects of aircraft overflights on urban populations in the vicinity of airports, a detailed literature review (ref. 2) revealed a shortage of information on the subjects of en route aircraft sound, aircraft sound in wilderness settings, or the acoustic effects on a park or wilderness visitor population. The WACOS, therefore, is breaking new ground, and we must rely on research in related areas as there is none directly related to the topic at hand. Presented below is a brief synopsis of the available literature in topics of interest with some relationship to the Wilderness Aircraft Overflight Study.

Wilderness Managers' Views of Aircraft Overflights

A review of four surveys of wilderness unit managers conducted over the last 7 years (ref. 3) identified the cumulative rank order responses for the significance of external threats (human activities outside the area boundaries which degrade valued characteristics of nature) to wilderness areas. Military operations, namely overflights, were ranked first among all threats listed, with airborne pollution ranking a close second. The "military operations" category may be somewhat misleading in that it refers primarily to military aircraft overflights, and some respondents may have included commercial or private air traffic within the air category (ref. 3).

A study of Forest Service managers of wilderness areas (excluding Alaska) was conducted by the Forest Service in the fall of 1988. Responses were received for 90 percent (282/314) of the wilderness areas sampled. Of the 282 wilderness areas for which responses were obtained, 152 areas (53.9 percent) identified a concern in one or more categories of aircraft overflights. Wilderness managers identified 130 wilderness areas (46.1 percent) with no identified aircraft overflight problems. Some wildernesses near commercial airports were impacted by 12 to 13 aircraft overflights per hour! Wilderness managers perceived military overflights to be a greater problem in wilderness areas than other types of aircraft, even when there was less than one flight per day. Of the 152 areas with aircraft overflight problems, 93 (61 percent) indicated military aircraft were a problem. When considering those managers that indicated there were aircraft overflight problems even though they had less than one flight per day, 45 managers indicated that the problems were from military aircraft, 16 mentioned general aviation, while only 2 managers indicated that commercial aircraft were a problem.

Another study of Forest Service managers of districts containing officially designated wildernesses was conducted by the General Accounting Office in the spring of 1989 (ref. *). Although not specifically directed at overflight issues, some survey questions dealt with "aircraft transport" within Forest Service wildernesses. The data provided below indicate that the majority of wilderness district managers reported no aircraft transport during fiscal year 1988, but more than 7 percent of those managers able to respond to this question indicated that they had more than 25 aircraft transport occasions during that time. That study did not distinguish the type of aircraft transport, however (military, sightseeing, helicopter, en route aircraft, and so forth).

Number of Aircraft Transports	Number of Wilderness Ranger Districts
0	155
1 - 10	87
11 - 25	11
26 - 50	6
51 - 100	5
> 100	9
no basis to judge	20

*General Accounting Office, 1989. Survey of U.S. Forest Service Management of Wilderness Areas. unpublished study conducted by the GAO, spring 1989.

Additionally, that study found that 24.6 percent (71/289) of reporting districts said that air transport (helicopters or airplanes) was specifically allowed in this wilderness by either the legislation that enacted that wilderness or in the Wilderness Act of 1964, as of September 30, 1988. Also, 7 percent (15/215) of reporting districts said that airfields or heliports existed legally or illegally in the portion of the wilderness within their district. (See footnote, preceeding page.)

Another indicator of the severity of the problem of aircraft overflights of national parks and Forest Service wildernesses is given by the establishment of advocate groups who are trying to modify, reduce, or prevent overflights of rural areas, including parks and wildernesses. "SKYGUARD," located in Reno, Nevada, is one such group. SKYGUARD is a grass roots organization born during a 1986 "Save Our Skys" conference sponsored by the the Rural Coalition and Citizen Alert organizations, which included environmental leaders of the West and experts on military airspace issues. Representatives from most western states were present at that conference. The idea for SKYGUARD's toll free telephone number (1-800-759-4827) was developed during that conference to enhance communications among people and organizations that perceived problems with military aircraft overflights. Although not originally a major function of the organization, SKYGUARD has become a national clearinghouse of aircraft overflight technical information, and complaints related to those overflights *

"Close encounters with military overflights are occurring with increasing frequency due to DOD changes in defense strategies which emphasize low-level altitude flight training" (ref. 4). The FAA recommends that pilots--both civilian and military--not fly below 2,000 feet in national parks and Forest Service wildernesses, but the agency's advisory does not carry the force of law.

From the information presented above, there are indications that aircraft overflights of Forest Service wildernesses and national parks are a problem in at least some areas. Few scientific studies have been conducted where the visiting public was contacted in a systematic fashion. Recently, however, public concern over the issue of aircraft overflights of national parks and Forest Service wildernesses led to creation of Public Law 100-91 in 1987. In response to that law, the Forest Service and National Park Service are jointly participating in an interagency study of aircraft overflights to assure compatibility of study results and maximize cost effectiveness. The primary study goal is to "perform research to define the relationship between aircraft overflights of Forest Service wilderness and National Park Service areas and effects on visitors and resources."

Wilderness Users--a Brief Background

Outdoor recreation sociology is a fairly new science, with the first major scientific studies being conducted for the Outdoor Recreation Resources Review Commission in the early 1960s (ref. 5). Since that time, there have been many studies of users of national parks and wilderness areas.

A summary of the available research on wilderness users (ref. 6) showed that wilderness users come from a variety of backgrounds and recreate in a

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* Bukowski, Grace. 1989. Personal communication with representative from SKYGUARD, P.O. Box 5391, Reno, NV 89513, (1-800-759-4827) on September 5, 1989.

variety of ways; however, some generalities can be made. Wilderness visitors are primarily young adults, males, highly educated, have professional or technical occupations, moderately high incomes, and are predominantly from local or regional areas. These visitors have low membership in conservation organizations, are urban residents, have considerable previous experience, and most often come in family groups. Wilderness recreation use is distributed unevenly among areas, within areas, and over time. Parties typically are small; most often use the wildernesses without outfitters; stay only a short time (a few hours or a few days); and engage in multiple activities, with hiking, fishing, and photography being the most common.

It is important to recognize the differences between the typical situation encountered by respondents to community airport noise studies and the typical wilderness recreation experience that will be studied in the WACOS. In a community noise study, the respondent reports the acoustic environment he or she has become accustomed to over a long period of time at his or her residence. In a wilderness recreation setting, the situation is quite different. The respondent is in a possibly unfamiliar environment, and is there for only a short period of time--perhaps as little as a couple of hours, or perhaps as long as a few days. Considerably more effort and expense is required to have a wilderness recreation experience than to stay at home. The recreationist must set aside sufficient leisure for the visit, arrange for transportation, usually make arrangements with others to accompany him, acquire any needed equipment, and develop plans for a recreational experience. Therefore, there is a much higher opportunity cost in terms of an investment in time, equipment, and personal resources for even a short wilderness visit than to simply stay at home. One might theorize, therefore, that recreationists would be more critical of any sort of detractions from their wilderness visit than they would be at home. On the other hand, because the recreationist is only at the wilderness area for a short time, perhaps coping mechanisms would allow him or her to simply put up with annoying aircraft overflights, where in a residence setting that same person might choose to take action to reduce or remove the annoyance.

Noise in Remote Recreational Settings

One of the only publications on recreationists' reaction to noise (ref. 7) included aircraft noise. The central thesis of that publication is that people's acceptance of noise in a recreation environment is in large part determined by the character of recreation resource. That article describes the Outdoor Recreation Opportunity Spectrum, which establishes a gradient of characteristics of outdoor recreation lands, from primitive to urban areas. Along this gradient, acceptability of human-made noise varies with the character of the recreation opportunity, with human-made noise being less acceptable in the more primitive settings, such as wilderness areas and remote portions of national parks. The sounds in primitive recreation areas are primarily natural background sounds (such as wind or water), and both mechanical and unnatural nonmechanical sounds are inappropriate.

People who choose a particular type of recreation opportunity (primitive, modern, and so forth) probably hold somewhat similar notions of what is appropriate and in keeping with these kinds of places (ref. 7). Some of these notions become widely and stongly held norms that govern behavior and set

standards of appropriateness and acceptability in a specific setting far more effectively than agency regulations. Consequently, standards of acceptability of the loudness, repetitiveness, or duration of sounds in recreation environments should be established only in terms of the Outdoor Recreation Opportunity Spectrum.

Three researchers propose that a person's expectations modify the acceptability of noise levels--a person with experience in a particular area would have more realistic and strongly held expectations than a novice (ref. 7). Those authors also propose that two personal characteristics of a listener may also affect the impact of a given sound source on the listener--knowledge of the source's presence and attitude toward the source. If a listener has previous knowledge that the source will be emitting sounds, detection is more likely than if the source is completely unexpected. Additionally, the message of a sound may also influence its acceptability. For instance, hikers likely would not be bothered if they were to hear other hikers chatting. But, if they heard motorcycles--or other hikers who were screaming and yelling--they probably would be bothered to a significant extent (ref. 7).

Sounds, then, only become unacceptable according to the criterion of appropriateness within a specified opportunity, rather than at any absolute level. By this logic, recreationists in a primitive area such as a wilderness or remote portion of a national park who held expectations of a quiet environment would find even the faintest sound at any time from a chain saw, motorcycle, or airplane to be a disruption of their recreation experience.

UNIQUE SOCIOLOGICAL ISSUES

The WACOS provides the opportunity to combine two areas of research for the first time. Therefore, this research will set precedents in definitions of terms, selection of appropriate metrics, and methods used for data gathering. Additionally, a number of sociological issues may be important in determining recreationists' reaction to aircraft overflights, but it is not yet known which of these issues is most important. Therefore, all of these issues should be considered in the design of this research. These issues are discussed in turn below.

"Special Places" and Off-Site Users

"A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain" (Public Law 88-577, the 1964 Wilderness Act).

Wilderness areas and national parks are special places. National parks have been called "Crown Jewels" of the country. Wilderness areas are intended to remain "untrammeled by man" in perpetuity. Many visitors specifically seek out these areas precisely because of their pristine nature. Therefore, because of the special character of these lands, users of these areas may place even more stringent levels of acceptability of intrusions by man than for other recreation areas or possibly even their home environments. Additionally, there

are "off-site users" who may not even visit the areas, but may respond to newsletters or articles from environmental organizations by taking action such as writing their political leaders to solve problems they may have never personally encountered.

Satisfaction/Annoyance

There are many reasons for establishment and maintenence of parks and wildernesses beyond recreational use of these areas. These reasons include: preservation of ecosystems and gene pools, scientific values, educational values, social values, and even commercial values. But, of major consideration to managers of wildernesses and parks is the satisfaction of the visiting public.

Unlike community aircraft noise studies where the dependent variable of interest is generally "percent highly annoyed," recreation studies often consider "percent highly satisfied." The merging of these two fields and concepts raises the issue of the appropriate sociological dependent variable--percent highly annoyed or percent highly satisfied. Should we strive for a low level of annoyance or a high level of satisfaction? This is a policy level decision, beyond the scope of this paper, but nonetheless an issue which must be resolved before additional extensive research is conducted in this area.

Additionally, rather than measure annoyance or satisfaction, perhaps other measures of the impact of aircraft overflights on park/wilderness visitors should be considered in the WACOS. These metrics include detectability (audibility by a person actively listening for aircraft), noticeability (audibility by a person not engaged in active listening for aircraft), intrusion (interference in a recreational activity, caused by aircraft overflights), annoyance (as used in conventional airport noise studies), and/or a behavioral response (such as leaving the area, complaining to authorities, taking some measure to modify or reduce the overflights, or not returning to the area because of the overflights).

When to Measure Impacts?

Another difference between the WACOS and conventional aircraft annoyance studies is a temporal one. In community studies, residents are asked about the long-term effects of the aircraft overflights on their level of annoyance. But people recreating in wildernesses and parks are, by definition, visitors who may or may not choose to return. There are four time periods of interest when aircraft impacts may be of importance to the WACOS: (1) at the time of the overflight; (2) at the conclusion of the trip, when an evaluation of the entire experience is being made; (3) at home, when the impacted individual is presenting an evaluation of the experience to others; or, (4) when a decision is being made to return to that area or choose another area for their next trip. There are valid reasons for considering each of these response measurement periods, but a decision as to which (if any) is most important has not been made at the time of this writing.

Transient Population and Frame of Reference

Most studies of reactions to aircraft noise are related to one's home environment. Respondents to these studies are faced with an acoustic environment with a relatively regular pattern of aircraft noise over an extended period of time. In a wilderness or park setting, people are nearly always visitors, staying only a short period of time, and in many cases are at the new location for the first time. These individuals have a different frame of reference. Because of the lack of previous studies of the reaction of transient populations to aircraft noise, we do not know what frame of reference these individuals are using. They may be comparing the acoustic environment with their residence or place of employment, or may be comparing it to other parks or wildernesses they have visited in the past, or even comparing the real-world environment to one they have imagined as the idealized wilderness environment, devoid of any evidence of the modern world.

Motivations

Motivations are an important topic in outdoor recreation sociology, and are of critical importance in determining if the recreational opportunities provided are meeting the needs of the people that are using the areas. The motivations for coming to a national park or wilderness area are many and varied. The more common motivations can be categorized as: sharing enjoyment with others; escape; seeking a sense of competence, self-esteem, or achievement of self-worth; or a desire to be in pleasant surroundings (ref. 8).

It is important to accept that these reasons are all valid uses of natural environments, but that one's motivations can change from one recreation experience to another, or even during the same recreation experience. An individual's motivations for coming to a wilderness area or park are a central issue for the WACOS, because an individual's motivations will likely influence their perception of the environment they encounter and thus modify their level of satisfaction (or the annoyance) with the recreational environment. For example, someone seeking to participate in rowdy activities with their companions may not place much emphasis on the characteristics of the environment and may not even notice aircraft overflights, while at another time that same person may be seeking escape from civilization to consider some spiritual question, and even a single aircraft overflight might ruin their experience.

Social Environment

The large majority of outdoor recreational experiences occur in a social setting. It has been shown that the individuals with whom one recreates influence one's recreational patterns and activities in an outdoor setting (ref. 9). It is likely that one's recreation partners influence an individual's reaction to a variety of attributes of a wilderness experience, including aircraft overflight noise. Social factors that may influence reaction include group size (which could affect the ambient noise level), experience and specialization level of group members, past experiences of group members, and stongly held opinions of influential group members.

Conflict

The study of conflict among recreationists is a common area of inquiry in outdoor recreation research. Several case studies have shown that conflicts arise between recreationists participating in specific activities, such as anglers and motorboaters, or hikers and horseback riders. One area of consideration for the WACOS is determination of possible conflict between aircraft overflights and specific types of recreationists. For example, wilderness visitors seeking solitude or enjoying wildlife photography may be highly impacted by aircraft overflights, while others seeking only a social experience may not be impacted at all.

Coping Behavior

Visitors to wildernesses often have a considerable investment in both time and money to reach these areas. It has been suggested, therefore, that these people may choose some type of coping mechanism to reduce annoyance from overflights, rather than let the intrusion interfere with the enjoyment of their visit. Such coping mechanisms could include: ignoring the overflights; justifying the overflights for a purpose they consider necessary; focusing on some aspect of overflights they may enjoy, rather than on the intrusion; or some other coping mechanism.

STUDY GOALS AND OBJECTIVES

The WACOS core team understands the legislation mandating this study to require the following primary study goal:

> Perform research to define the relationship between aircraft overflights of Forest Service wildernesses and National Park Service areas and effects on visitors and resources.

Specific project objectives are as follows:

1. Determine the correlation between aircraft noise and visitor response in a wilderness/park setting.

2. Select the best methods considering the timelines and cost as well as a scientific merit for accomplishing study goals;

3. Identify the most important visitor responses to aircraft overflights and determine how they should be measured.

4. Identify the acoustic variables of greatest concern to visitors and the level of precision needed in the acoustic measurement program.

5. Describe the effectiveness of SFAR 50-2 in restoring the natural quiet at Grand Canyon National Park.

6. Identify any other impacts of overflights on sensitive resources (historic or prehistoric structures, wildlife, and so forth).

7. Develop a planning tool to assist field managers in assessing the impact of overflights on the park/wilderness environment.

8. Conduct lab or controlled studies as necessary to identify the most important aircraft noise/dose parameters.

9. Determine how the motivations and satisfactions of air tour passengers are related to those characteristics of flights which impact wilderness visitors.

10. Study the relationship between visitor safety and aircraft overflights.

11. Determine the impacts of sonic booms on wilderness users and park visitors.

Specific end products desired in the WACOS include: (1) a relative ranking of acoustic annoyances; that is, in a list of annoying sounds in wildernesses and parks, where do aircraft rank?; (2) an absolute ranking of aircraft overflight impacts; that is, what percentage of wilderness and park visitors are impacted by overflights either by an increase in annoyance or a decrease in levels of satisfaction; (3) a ranking of aircraft types by annoyance level; that is, in this rank, where do different types of aircraft fit (en route aircraft, sonic booms, military training flights, sightseeing aircraft, helicopters, general aviation, administrative flights, and others); (4) identification of annoying characteristics of aircraft overflights; that is, what characteristics of the sound are most bothersome (sonic booms, time above, LDN, detectability, tone, and so forth); (5) identification of recreational circumstances related to aircraft overflight annoyance, including social group, motivation, activity, time of day, presence of pack stock, and so forth.

METHODS

At the time of this writing, methods for obtaining the information desired have not been finalized. The study design will be finalized in consultation with the selected contract research team. The information provided below presents a preliminary discussion of methods likely to be used to gather the information required by this study, arranged chronologically.

The study is envisioned as a three-phased project, which is described in more detail in the following paragraphs. Most of the work will be devoted to determining the relationship between the aircraft noise environment and the response of park/wilderness users. The Forest Service final report will be completed by May 1991. The National Park Service final report is anticipated to be completed in 1993. To ensure consistency of results, the Forest Service and National Park Service have selected a single nationally known contract research team who will perform most of the work on a task-order basis. To ensure cost effectiveness, state-of-the-art white papers rather than original research will be used where costs are prohibitive, and smaller studies will be performed in-house or by other methods.

The first phase of the project is designed to finalize the overall study design and determine the range of responses of wilderness and park users to aircraft overflights. This phase will include study design meetings with experts in the field from acoustics, psychoacoustics, and wilderness sociology. A series of pilot tests will be conducted using questionnaires, acoustic measurements, focus groups, meeting with managers, participant observation, and possibly other techniques in a convergent validity framework. Information gained in this phase will assist development of later phases of the WACOS.

The second phase of the project is designed to assist in identification of the most important noise-dose parameters and visitor responses which should be subject to intensive field investigation. Since virtually no previous work has been accomplished in the field of investigation of aircraft overflight effects on dispersed recreationists in natural settings, there is a tremendous number of variables (aircraft type, aircraft altitude, aircraft use, aircraft sound characteristics, and visitor characteristics) which need to be investigated to perform the necessary analysis to define the relationship specified in the overall project goal outlined above. Due to high costs of field data collection, it is desirable to reduce the number of variables to be investigated in the field portion of the study. This work will be accomplished through lab and pilot studies.

The final phase of the WACOS consists of concurrent detailed sociological and acoustical field studies and preparation of final reports. In Forest Service wildernesses, this phase will be conducted during the summer and fall of 1990. It is anticipated that 10 to 20 Forest Service wildernesses will be studied. Forest Service data analysis, interpretation, and report writing will be done during the fall and winter of 1990, with the final Forest Service report to be due in May 1991. For National Park Service areas, this phase will likely be conducted in 1991 and possibly 1992.

At the time of this writing, plans are being finalized to conduct a pilot study at a wilderness area in the northern Rocky Mountains this fall to test a variety of methods for possible use in the primary field data collection in 1990 and to reduce the number of sociological variables of interest. This pilot study will investigate sociological and acoustic issues related to overflights. Sociological questions to be answered include identification of the range of possible responses the recreating public may have to overflights, what aspects of overflights create the most annoyance, and which social or activity circumstances are correlated with high levels of annoyance to aircraft overflights.

DISCUSSION/CONCLUSION

The Wilderness Aircraft Overflight Study provides an opportunity to advance both the fields of wilderness sociology and acoustics. While responding to the congressional legislation requiring this study, this research could also open new areas of investigation into the influence of the acoustic environment on recreationists' overall satisfaction level. Findings may help identify appropriate noise levels depending on the type of recreational setting--it is likely that in some recreational settings, such as amusement parks or dance

clubs, a high level of human-made sound enhances the recreational experience, while in remote wilderness settings any human-made sounds are considered an intrusion. Ultimately, it may be possible to use information obtained from this study and others that may follow to develop a better understanding of the importance of acoustics to recreation satisfaction and to improve the public's recreation environment. Additionally, further insights may be gained as to aircraft acoustic issues in rural areas, which could be important in developing future regulations related to military training routes, military operating areas, commercial flight paths, and general aviation regulations. Consideration of the importance of the ambient sound level and the transient nature of the populations in these areas may lead to new acoustic metrics and methods appropriate to future studies.

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WHEN PROPFANS CRUISE, WILL LDN 65 FLY?

Fred Mintz and William Dickerson
U.S. Environmental Protection Agency
Washington D.C.

INTRODUCTION

The question I would like to explore in this paper is the type and extent of response that may be expected from the persons exposed to the noise of propfans cruising overhead. The cruise mode is of particular interest because it appears that it is in this mode that the propfan airplane noise differs substantially from the noise of present jet-powered airplanes.

Early test data on propfan engines suggests that noise levels on the ground under the flight track of commercial propfan transports may approach 65 decibels. To explore the reaction of the exposed population to repeated noise levels of this magnitude, it may be helpful to review some of the pertinent literature on the effects of environmental noise.

TECHNICAL DETAILS

1. Protective Noise Levels

In EPA Report 550/9-74-004, the so-called Levels Document (ref.1) the Agency, as required by the Noise Control Act, identified the environmental noise levels (low enough) to protect the public health and welfare. Chart 1, from the Levels Document, shows that Ldn 55 is adequate to protect against outdoor activity interference and annoyance.

Chart 2, from Guidelines for Preparing Environmental Impact Statements on Noise (ref.2) shows the annoyance dose-response function that largely formed the basis for the selection of Ldn 55 as the "protective" level. Of interest also is Chart 3, from EPA's Protective Noise Levels (ref.3). These data, based on a number of community noise studies, show the level of community response to various levels of aircraft noise exposure.

Based on the foregoing findings, the Interagency Committee

on Noise in 1980 published the Guidelines for Considering Noise in Land Use Planning and Control (ref.4). Chart 4, from that document, shows that Ldn 65 was selected as the level at which "significant" noise exposure begins.

It should be noted that EPA's identification of Ldn 55 was made without consideration of the question of cost or practicality of achieving such a level of environmental noise. The Interagency Guidelines, appropriately enough, took into consideration matters of practicality and cost.

2. Sleep Disturbance due to Noise

What is the basis for judging sleep disturbance due to noise? The best data currently available to us is based on laboratory tests of the effects of noise on sleeping persons. Chart 5, from Fig. 8-2 of EPA's Desk Reference to Health and Welfare Effects of Noise (ref.5) shows the probability of noise-induced awakening as a function of A-weighted Sound Exposure Level (SEL).

From this figure, it can be seen that, for a noise event with SEL = 64 dB, the probability of a sleeping person awakening is 20 per cent. The probability of awakening (P_a) is 10 per cent for SEL = 54 dB.

Since these data are based on the SEL at the sleeper's ear, the noise reduction between exterior and interior should be added to relate the probability of awakening to the exterior SEL. Taking 15 dB as typical for a single-family residence in the summer, and 20-25 db in the winter, the corresponding exterior SEL values for awakening are (see Chart 6):

* for Pa = 10 %, SELs(summer) = 69 dB and SELw(winter) = 74-79 dB;

* for Pa = 20 %, SELs = 79 dB and SELw = 84-89 dB.

3.Speech Interference due to Noise

It is well known that noise can interfere with speech communication. Chart 7, from Figure 10 of EPA's Protective Noise Levels, shows this effect quantitatively. From this figure, it is apparent that sentence intelligibility begins to degrade markedly at a sound level of 65 dB.

However, for consideration of interference with the educational process, a more stringent criterion may be necessary, particularly for the lower grades, where vocabulary is not well-developed in the pupils, and word intelligibility is crucial. In a US DOT/FAA Report to Congress, July 1977, on the Feasibility... of...Sound-Proofing Public Schools..., a level of 45 dB was

selected as the threshold of speech interference in classrooms (according to K.L.Kaufman (ref.6)).

Consider a "typical" airplane flyover, in which the sound level remains within 10 dB of the maximum for 10-20 seconds: if the maximum is 55 dB, the Single-event level (SEL) will be about 8 dB above the maximum sound level (Lamax) or about 63 dB. For a building with an outdoor-to-indoor attenuation of 20 dB, the corresponding outdoor SEL is about 83 dB.

4. Noise Exposure due to Cruising Propfans

Now, you may ask, what does all this have to do with cruising propfan airplanes? Well... let's look at the projected sound levels under the flight path of a propfan cruising at 35,000 feet. From NASA and other test data it is not unreasonable to anticipate maximal A-weighted sound levels (L_A max) around 65 dB, with corresponding SEL values possibly as high as 73 to 75 dB. It should be noted that these levels are 15 dB or more above those encountered from current transport airplanes at cruise altitude. Typical data from a propfan test bed aircraft are shown in Chart 8 (from ref.7).

Consequently, one may expect at least 10 per cent of the sleepers in a band a few miles wide under the flight path to be awakened by each overflight (nighttime.) It would be possible, given the population distribution data, to estimate the numbers of persons involved; for purposes of this discussion, we can reasonably infer that a comparatively large number of persons will be awakened by each overflight.

If a large fleet of propfans is operating, this will occur many times per night. Such a situation well may lead to a substantial volume of complaints. It should be added that, at the levels considered here, speech interference does not appear to be a significant factor.

5. Single-Event Levels vs DNL

It should be noted that, even with 100 overflights (at SEL = 75 dB) in 24 hours, 10 % of them at night, the DNL contribution would be less than Ldn 50 (see Chart 9.) So here we have a situation where the DNL is well below the level that requires mitigative action in the vicinity of an airport, but the number of awakenings is highly likely to generate many complaints.

A case in point is that of Westover Air Force Base near Chicopee, Mass. The Air Force was considering certain changes in operations of military aircraft, along with the optional introduction of commercial cargo aircraft activities. In the EIS for this proposed action (ref.8) the analysis disclosed that the anticipated nighttime operations of cargo aircraft could expose

some 40,000-plus local residents to exterior SEL values of 80 dB or higher, several times per night.

The next chart (10) shows that the SEL 80 boundary extends well beyond the Ldn 65 contour. Currently accepted dose-response data, indicating a probability of awakening of about 20 %, suggested that this exposure could cause multiple awakenings of 8,000 or more persons each night. Apparently largely as a result of these considerations, the Air Force decided to postpone indefinitely the introduction of the nighttime commercial cargo operations.

6. **EIS Reviews**

Under Section 309 of the Clean Air Act and the National Environmental Policy Act (NEPA), EPA is charged with reviewing and commenting on the environmental impact of (applicable) actions of any Federal department or agency. In accordance with this responsibility, the Office of Federal Activities (OFA) has reviewed a number of Environmental Impact Statements (EIS's) and Environmental Assessments (EA's) issued by the FAA concerning improvements, expansion, or construction of airports.

It is not uncommon, in the public comments section of these documents, to find complaints from individual citizens and community groups about the noise intrusions caused by the airport operations. In many instances, these complaints concern noise in areas outside the Ldn 65 contours. Partly as a result of these reviews, EPA and the FAA have been involved in correspondence and discussions concerning the question of supplementing the standard DNL analysis, either by extending the DNL analysis beyond the Ldn 65 contour, or by introducing certain single-event analyses.

CONCLUSION

The impending introduction of a new generation of commercial transport airplanes with propfan propulsion systems creates the apparent potential for repeated sleep disturbance and other annoyances due to the noise on the ground from these airplanes cruising overhead. Many complaints may emanate from the persons so exposed, even though the DNL is substantially below 65 dB, FAA's criterion for "significant" noise impact (exposure.)

Experience suggests that the earlier attention is devoted to consideration of mitigative approaches, the greater the probability of forestalling the impacts and resultant complaints, at reasonable cost.

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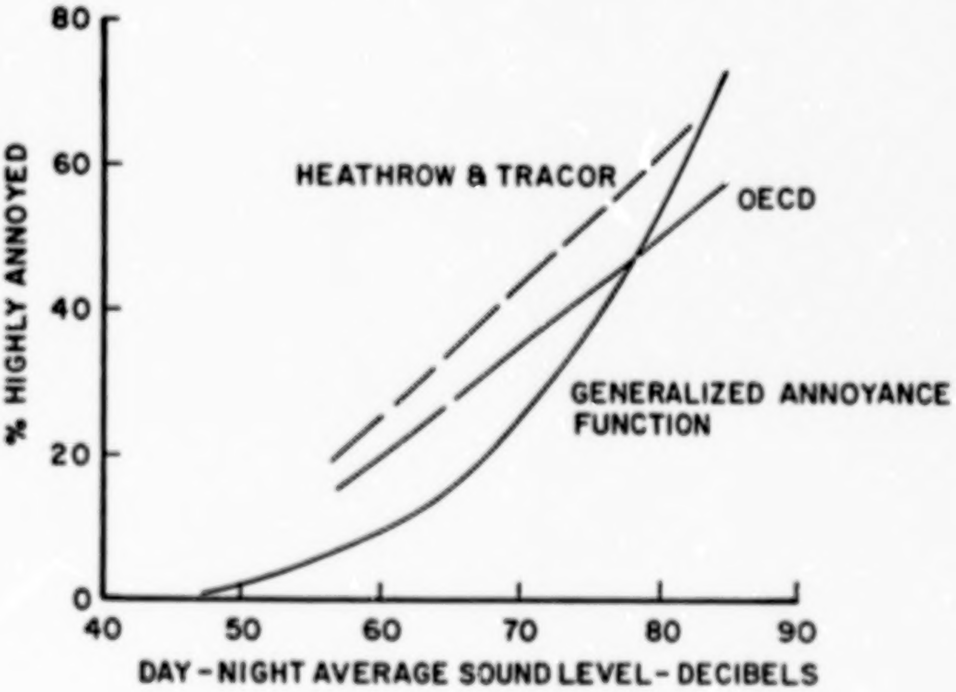
Yearly L_{dn} Values That Protect Public Health and Welfare with a Margin of Safety

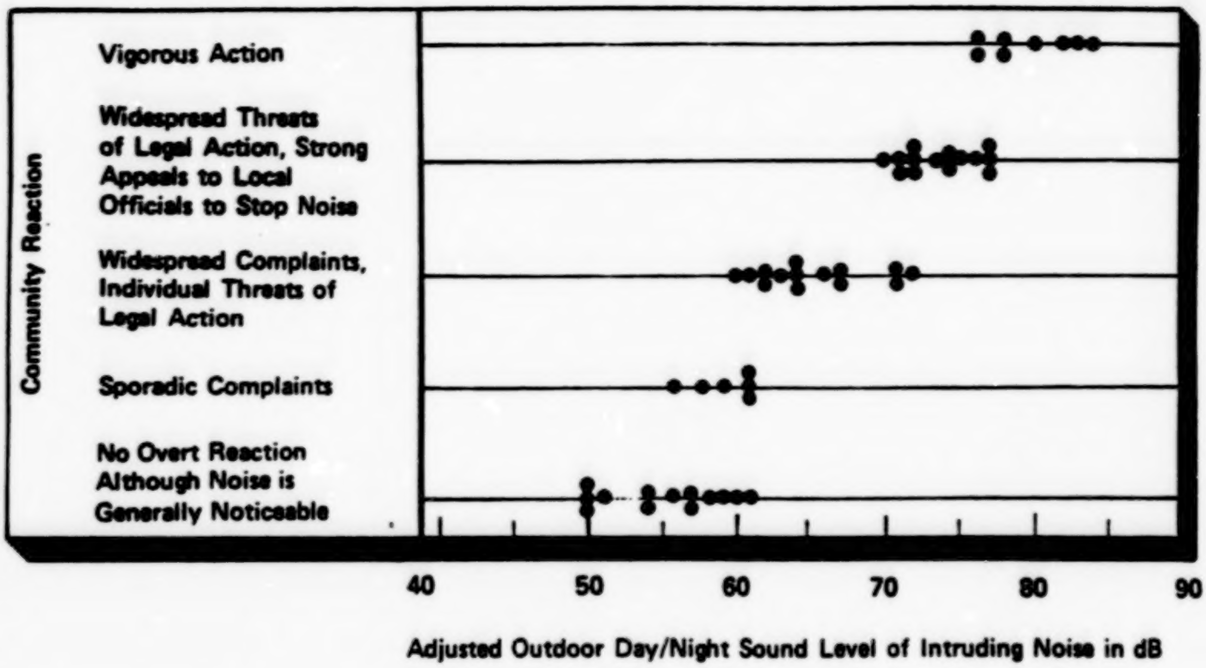
EFFECT	LEVEL	AREA
Hearing	$L_{eq(24)} \leq 70$ dB	All areas (at the ear)
Outdoor activity interference and annoyance	$L_{dn} \leq 55$ dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(24)} \leq 55$ dB	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	$L_{dn} \leq 45$ dB	Indoor residential areas
	$L_{eq(24)} \leq 45$ dB	Other indoor areas with human activities such as schools, etc.

CHART 1



Comparison of Generalized Annoyance Function with Previously Published Functions Derived from Social Surveys Around Airports.

CHART 2



COMBINED DATA FROM COMMUNITY CASE
STUDIES ADJUSTED FOR CONDITIONS OF EXPOSURE

CHART 3

NOISE ZONE CLASSIFICATION

Noise Zone	Noise Exposure Class	Noise Descriptor: DNL[1] Day-Night Average Sound Level	Noise Descriptor: L_{eq}(hour)[3] Equivalent Sound Level	Noise Descriptor: NEF[4] Noise Exposure Forecast	HUD Noise Standards
A	Minimal Exposure	Not Exceeding 55	Not Exceeding 55	Not Exceeding 20	"Acceptable"
B	Moderate Exposure	Above 55[2] But Not Exceeding 65	Above 55 But Not Exceeding 65	Above 25 But Not Exceeding 30	
C-1	Significant Exposure	Above 65 Not Exceeding 70	Above 65 Not Exceeding 70	Above 30 But Not Exceeding 35	"Normally Unacceptable"[5]
C-2		Above 70 But Not Exceeding 75	Above 70 But Not Exceeding 75	Above 35 But Not Exceeding 40	
D-1	Severe Exposure	Above 75 But Not Exceeding 80	Above 40 But Not Exceeding 80	Not Exceeding 45	"Unacceptable"
D-2		Above 80 But Not Exceeding 85	Above 80 But Not Exceeding 85	Above 45 But Not Exceeding 50	
D-3		Above 85	Above 85	Above 50	

CHART 4

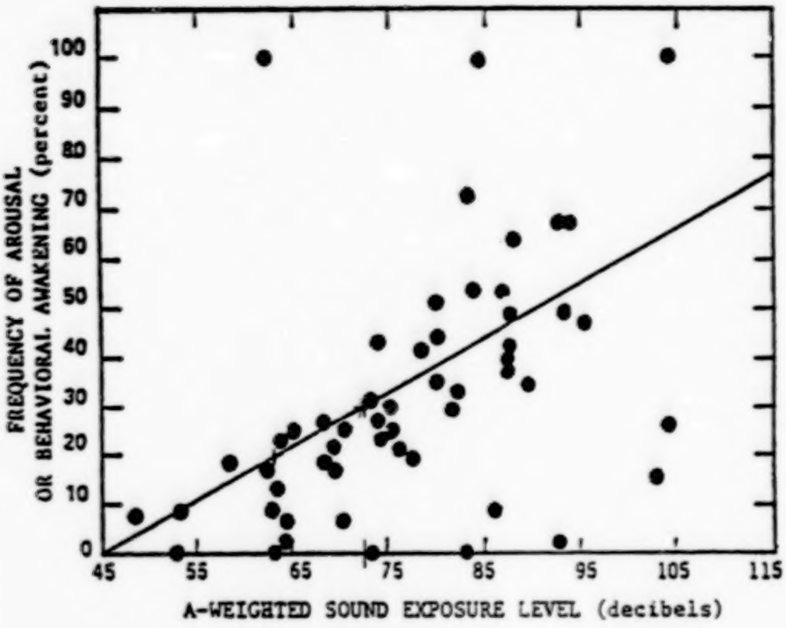


CHART 5

PROBABILITY OF A NOISE INDUCED AWAKENING

SOUND EXPOSURE LEVEL for SPECIFIED PROBABILITY OF AWAKENING

Probability (Pa)	SEL (Summer)	SEL (Winter)
10%	69	74-79
20%	79	84-89

CHART 6

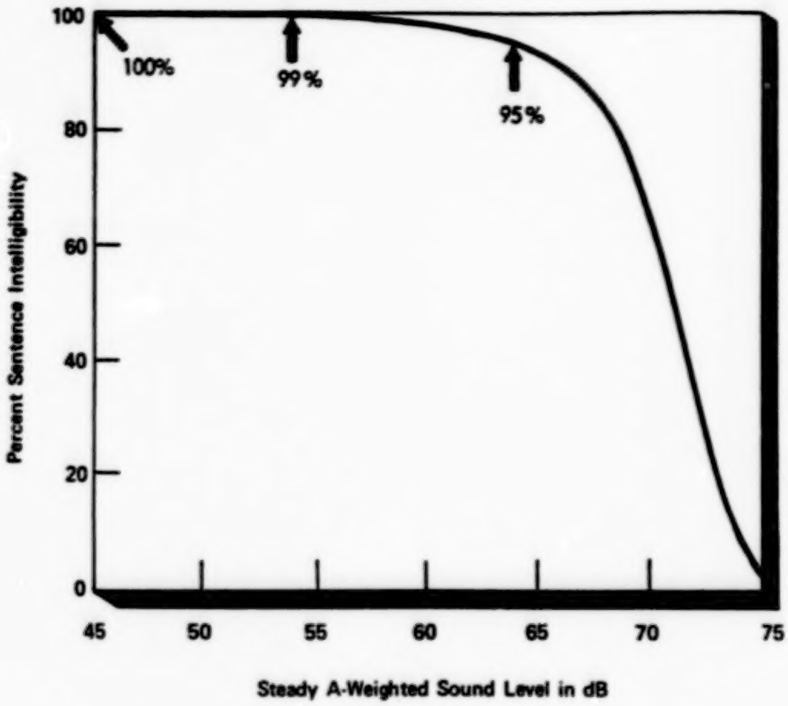


FIGURE 10. INDOOR SENTENCE INTELLIGIBILITY

CHART 7

PROPFAN NOISE DATA

Propfan Test Assessment (PTA)
En route Noise - 35000 ft

Location	SELmax	Lamax
On centerline	70.7	57.7
5 mi. West	60.7	53.9
5 mi. East	60.7	53.9
10 mi. West	57.4	49.1
10 mi. East	50.8	42.8

CHART 8

DNL CONTRIBUTION OF ONE EVENT

Assume event SEL = 75 dB

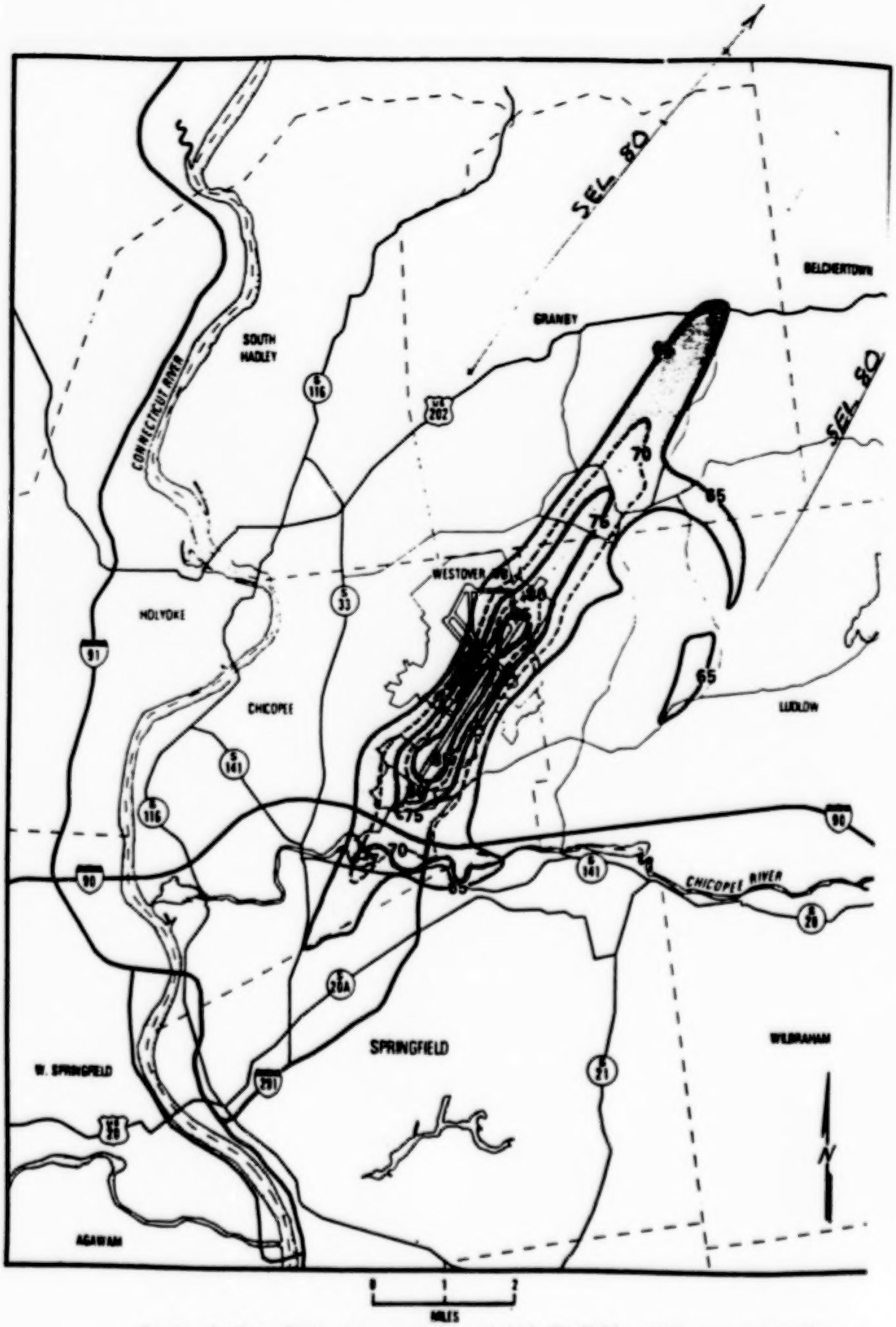
DNL contribution is

SEL - 10 log(86400) =
75 - 49.4 = 25.6 dB (daytime)
75 -49.4 + 10 = 35.6 (nighttime)

Assume 100 events, 10 at night
Daytime contribution is
25.6 + 10 log 90(=19.5) = 45.1 dB
Nighttime contribution is
35.6 + 10 log 10(=10) = 45.6 dB

Resultant DNL = 45.1 dB + 45.6 dB =
48.4 dB (Ldn 48.4)

CHART 9



Cumulative DNL for proposed (16 C–5A) military operations plus potential WMDC operations (with mitigation).

CHART 10

The Effect of Noise-Abatement Profiles on Noise Immissions and Human Annoyance Underneath a Subsequent Climbpath.

Maurice A. Garbell
M.A.G. Consultants, Inc.
San Francisco, California.

Introduction.

The most economical climbpath of a departing aircraft satisfies the variationally optimal altitude-airspeed management program defined by the the Euler-Lagrange principle, whereby the derivative of the rate of gain of energy of the aircraft with respect to the equivalent total-energy altitude must go to zero (Fig. 1).

In the practical operation of aircraft, an initial climb must be specified to raise the aircraft to an altitude at which terrain clearance and the restraints imposed by air-traffic-control considerations permit the pilot to accelerate the aircraft toward the optimal altitude-airspeed management program.

Noise-abatement climb procedures, in general, lead to adverse deviations of the climb profile from the variationally optimal profile. In fact, whereas climb procedures with deep power cutbacks may minimize the noise immissions in selected areas close to the departure end of the takeoff runway during the early takeoff climb, the further initial en route climb, when full climb power is restored, continues at altitudes (potential energy) and airspeeds (kinetic energy) that are lower than those attainable in a variationally optimal climb. Hence, the noise impact underneath the more distant points underneath the en route climbpath, and the annoyance imposed on and reported by residents there, are increased by the initial noise-abatement climb, in some instances substantially.

The en route noise problem created by initial noise-abatement climbouts with deep power cutbacks, is aggravated in climbs over rising terrain.

The Range of Distances Wherein Aircraft-Noise Immissions on the Ground can be Affected Substantially by Takeoff Noise-Abatement Climb Profiles.

En route noise immissions on the ground can be affected by the detailed characteristics of intended noise-abatement climb profiles and procedures to an extent of 10 or more nautical miles (n.mi.) from the start of takeoff roll of a large or heavy air-carrier-type airplane.

The present paper constitutes an extension and development of (1) suggestions submitted on May 8, 1982 to noise-abatement officials of the airports at Frankfurt, Federal Republic of Germany (FRG), and Zurich, Switzerland, and the air carriers Lufthansa German Airlines and SWISSAIR, (2) a paper presented in 1985 (Ref. 1), and (3) a paper presented on January 18, 1989 (Ref. 2).

Fundamentals of Noise-Abatement Climb Planning.

The only *a priori* requirement for any and all procedures of flight planning is *flight safety*. All other criteria are, within reason, variable and negotiable.

Several parameters and variables are fundamental to the safety, feasibility, and efficiency of a noise-abatement climb procedure.

(a) **Geometry**: The angle of the climbpath relative to the horizon, the angles and angular

velocities in pitch, yaw, and roll andthe profile of the underlying terrain.

(b) **Aerodynamics**: The angle of attack of the airplane, the true airspeed, and the thrust of the powerplant, the airframe configuration, and "decision points" along the climbpath and the lift and drag characteristics of the airplane at those points.

(c) **Meteorology**: The horizontal and vertical distribution of temperatures and wind velocities within the airspace around the airport.

Flight Safety and Energy Efficiency - Fundamental Requirements for a Climb.

In an initial climb of an aircraft, flight safety requires that (1) the climbpath of the aircraft continue to rise if the critical engine becomes inoperative, and (2) the aircraft can maintain straight flight against the yawing moment produced by the surviving engine(s).

Optimal Climb of an Aircraft.

The best energy utilization in climb consists in the attainment of the total energy ultimately required in cruise, that is, the sum of (i) the potential (altitude) energy and (ii) the kinetic energy (the square of the velocity), be attained in the shortest time or in the shortest distance or with the least consumption of fuel, Fig 1 (Ref. 3)

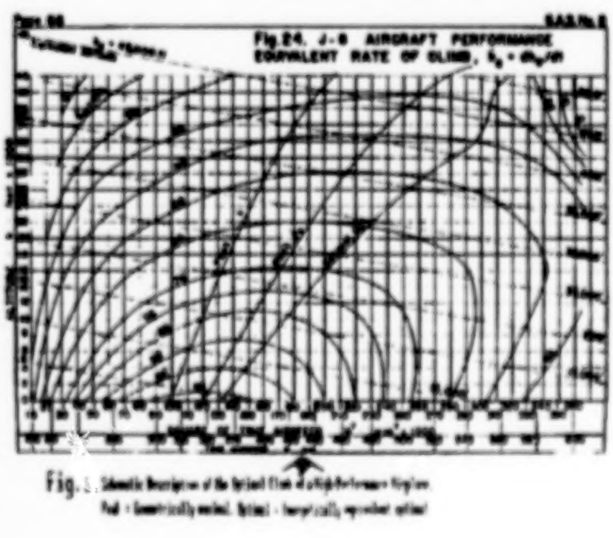


Fig. 1. [illegible]

Considerations of noise abatement and air-traffic control impose an initial compromise which affects not only the economy of the subsequent climb, but indirectly, the en route noise immissions underneath that climbpath.

The Minimal Deck Angle for Safe Flight.

Airworthiness regulations require that, with a powerplant inoperative, the aircraft must maintain straight flight at a specified climb angle. Many experienced pilots will maintain a climbing airspeed and deck angle at which the requirement could be met without any increase in thrust by the surviving engine.

This issue was discussed at a dedicated FAA Conference with especial reference to an initial climb with sharp thrust cutback shortly after takeoff (Ref. 4).

Optimal Climb Versus Steepest Climb.

The optimal climb requires higher airspeeds for the simultaneous attainment of a prescribed altitude (potential energy) and a prescribed cruising airspeed (kinetic energy) than a climb to the specified altitude alone.

Pursuant to the Euler-Lagrange principle of variational calculus, the optimal airspeed-altitude program runs along a curve which, in a h/Vt^2 diagram, connects the points at which the derivative of the function dh_e/dt (that is, the rate of gain of the equivalent or total energy translated into altitude) with respect to the equivalent altitude h_e, goes to zero (Fig. 1).

The Initial Climb.

In general, aircraft lift off the ground with lift-augmenting devices extended. Although the aircraft is then enabled to climb initially at a steeper angle and to attain a given altitude in less time and over a shorter distance, such procedure delays the acceleration of the aircraft toward its optimal climb program.

It follows that any deviation from the optimal airspeed-altitude program must of necessity

cause the aircraft to attain a lower altitude and/or a lower airspeed at any point of the subsequent climb. Any non-optimal initial climb must increase the noise immissions underneath the subsequent en route climbpath.

An initial unaccelerated climb with high-lift devices deployed delays the attainment of zero-flap maneuvering airspeed at which a 30-degree angle of bank, required for en route noise-abatement trajectories is practicable.

Factors That Govern Noise Immissions on the Ground.

1. For middle and high sound frequencies, a doubling of the distance reduces the sound-pressure immission levels by approximately 6 dB, subject to variations in air temperature and moisture content.

2. A reduction of the engine pressure ratio (EPR) is regarded as more effective for noise abatement that a greater gain in altitude at a higher EPR.

3. The deck angle and azimuth of the climbing aircraft affect the directional noise immission on the ground.

4. Greater airspeeds diminish the shear between the propulsive jets and the atmosphere and, hence, the sound emission therefrom.

5. Faster flight reduces the "time of sweep" of noise immissions and single-event noise-exposure levels on the ground.

6. A sharp turn during initial climb may expose points on the ground within that turn to a longer exposure time and, hence, a greater single-event noise-exposure level (Ref. 5).

Available Levels of Engine Thrust.

Aircraft with low-bypass-ratio engines (1.1 to 1.5) are normally flown with (1) *takeoff thrust* (maximum or reduced); (2) *maximum climb* thrust; and (3) "*quiet*" thrust.

Aircraft with high- bypass-ratio engines (2 to 5 or more) are operated with only the *takeoff thrust* and *maximum climb* thrust, because the further reduction of thrust would yield only limited noise-abatement benefits.

"Standardized" Noise-Abatement Climb Procedures.

No single noise-abatement climb procedure meets the needs of all configurations of terrain and noise-sensitive areas relative to an airport, any more than a single flap setting and takeoff thrust can be standardized for all runway lengths, takeoff gross weights, wind conditions, and airport elevations.

Takeoff-climb procedures have differing effects on the noise immissions within the area covered by the initial climb to approximately 3,000 feet altitude above airport level (AGL); all have differing effects, generally overlooked, on the noise impact of the en route climb.

The following summary description is illustrated with sketches derived from Ref. 5.

1. The so-called "*original ATA/FAA procedure*" (1973), better known in Europe as the "*IATA method*," (see Fig. 2).* The procedure initially consisted of a climb from liftoff to 3,000 feet altitude on takeoff power with takeoff-flap deflection; later, thrust was reduced from takeoff to maximum climb thrust at 1,500 feet, accompanied by a decrease in deck angle to

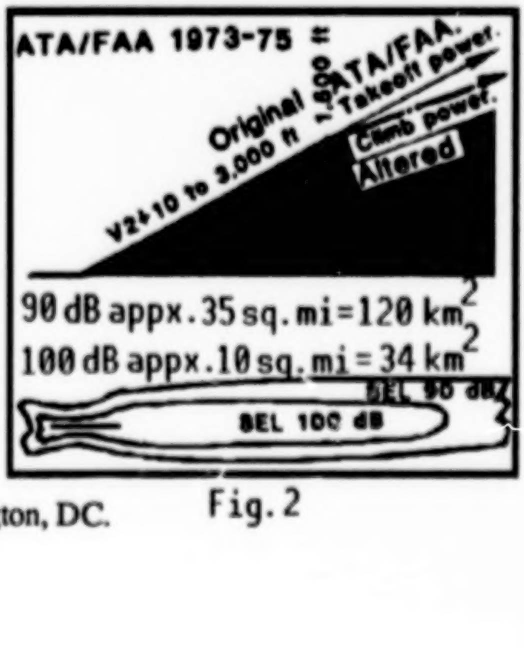


Fig. 2

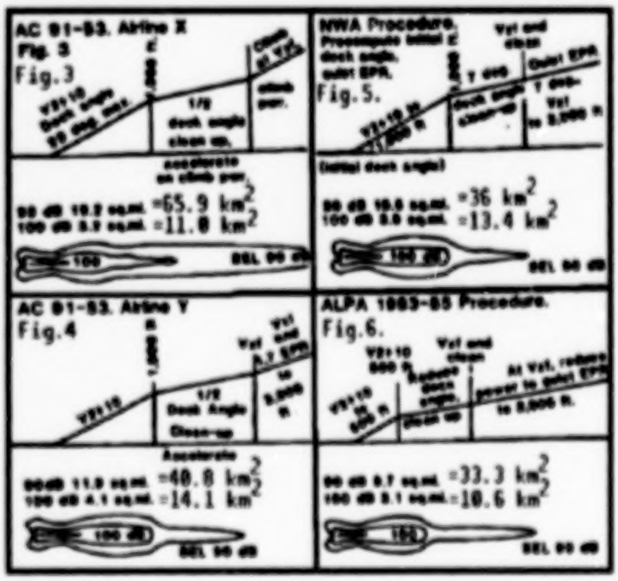
*Printed with permission of "The Air Line Pilot", Washington, DC. (See ref. 6.)

maintain V_2 + 10 kt to 3,000 feet and subsequent airspeed acceleration and flap retraction.

2. The so-called "*NWA-ALPA procedure*," in Europe termed the "*modified ATA (or IATA) procedure*," in which the climb at V_2 + 10 kt on takeoff thrust is terminated at 1,500 feet, the deck angle is reduced from about 18° to 7°-9° or a predetermined airspeed acceleration (0.5 to 1.5 kt/sec) or a specified rate of climb (500-1,500 fpm) is attained. The flaps are meanwhile retracted, and the engine thrust is reduced , until the "*quiet zero-flap airspeed, V_{ZF}*," at the "*quiet EPR*" is attained, where V_{ZF} is the zero-flap maneuvering airspeed.

Exhaustive theoretical analyses and flight evaluations proved the effectiveness of the noise abatement afforded by that procedure over the original ATA/FAA procedure to up to 10 n.mi. from start of takeoff roll (Ref. 6).

3. The so-called "*AC 91-53 Procedure*," adopted in 1978 by the Federal Aviation Administration (FAA) and the Air Transport Association (ATA), incorporated the substance of the "*NWA-ALPA procedure*" with the altitude of the start of reduction of deck angle, flap retraction, and thrust reduction reduced from 1,500 feet to 1,000 feet, with a 300- to 500-



foot transition band (Refs. 5 and 7). The "AC 91-53" procedure has since been applied by air carriers with a variety of modifications.

4. The so-called "*Orange-County noise-abatement climb procedure*" in which, with high-lift devices in their takeoff position, thrust is reduced at 1,000 feet or less to afford maximum noise abatement to noise-sensitive areas close to the departure end of the takeoff runway, while the requirements of 14CFR25 (Ref. 8) for a minimum climb angle (appx. 1°) with one engine inoperative are satisfied. Similar procedures have been implemented at Washington National Airport, La Guardia New York Airport, and elsewhere.

It has been the reported position of ALPA that thrust reduction, airspeed acceleration, and flap retraction in the interval between 400 feet and 1,000 feet altitude must be coordinated so that the FAR-25 minimum climb gradient in straight flight can be maintained with one engine inoperative and the remaining propulsive plant at its original EPR setting.

5. A "*New FAA Procedure*," deviating somewhat from the AC 91-53 procedure, first developed with cooperation from ALPA and others on Boeing 737 and MD-80 aircraft and later applied to heavier aircraft also. The procedure permits the following steps:

(a) Takeoff EPR and thrust to at least 400 feet altitude.

(b) Prescribed airspeed acceleration and flap retraction.

(c) EPR reduction to "*quiet EPR*" at V_{ZF} (or at V_{ZF} + 10 kt, if flap retraction is still in progress).

C[illegible]ued climb at V_{ZF} + 10 kt (or even at V_{ZF} [illegible] kt, if the rate of climb and the deck angle increase at low gross weights.

Figs. 3 through 6 illustrate the noise immissions resulting from the application of the various noise-abatement climb procedures, as deter-

mined by ALPA (Ref. 5). All have different energy-loss implications on subsequent en-route noise.

A Note on Meteorological Influences.

The rate and angle of climb of an aircraft is increased by a headwind component and a vertical headwind gradient, decreased by a tailwind component and a vertical tailwind gradient.

Atmospheric sound absorption depends on air temperature, moisture content, the wind velocity and turbulence, and their vertical gradients, and the presence of substantial precipitation bodies within the airspace.

The global effects of the afore-described aircraft-performance factors was investigated by United Airlines in the early 1980s at the instance of the writer through a simulation of departures from the San Francisco Airport in conditions of a sharp subtropical temperature inversion at levels from 1,500 to 2,500 feet.

Noise immissions underneath the en route climb at 10 to 12 n.mi. from start of roll were increased or reduced by 3 to 8 dB by the use of various initial climb procedures..

A Note on the Sufficiency of Existing Scientific Knowledge.

It is submitted that current knowledge about the effectiveness of noise-abatement procedures and, more especially, the "*downstream*" effect of noise-abatement climb procedures in the airport environment on the noise immissions on the ground during the subsequent en route climb, is still insufficient.

Existing knowledge about the three-dimensional distribution of noise emission from actual aircraft in free flight should be improved. The accuracy of experimental verification of the application of scaling laws to the prediction of flyover jet noise with different climb procedures is still not universally conceded.

Dependable observational data on the noise emissions and performance capabilities of aircraft in realistic normal flight operation over variously shaped terrain appear indispensable for an understanding of the impact of en route climbing noise of aircraft over noise-sensitive areas with low ambient noise levels.

Trouble in the Department of En Route Climb Noise.

A lack of understanding of the sources and nature of en route climb noise has led to instances in which presumable noise-abatement procedures have created substantial increases in subsequent en route noise impact.

(1) Noise Abatement for Fish, Noise Overburdening of Humans.

During early 1987, a strange and previously unexpected increase in noise immissions in the City of Brisbane, California, situated on the eastern shore of the San Francisco Peninsula between the City of San Francisco and its Airport drew attention to the en route noise problem that can be caused by ill-conceived would-be noise-abatement climb procedures on takeoff.

As depicted in Fig. 7, the San Francisco International Airport has two pairs of dual takeoff and landing runways, namely, the shorter runways 01-19 and the longer runways 10-28. The prevailing wind comes from the west.

Takeoffs on Runways 01 proceed initially over the waters of San Francisco Bay. Departures from Runways 28 pass over century-old residential areas spread over terrain rising toward the San Bruno Gap (= Saddle) between Mount San Bruno and the coastal hills.

By 1957, virtually all departures took off from Runways 28. Severe complaints by the communities in the San Bruno Gap arose, and, pursuant to a proposal by the writer, the air carriers adopted a preferential runway procedure with most departures taking off from Runways 01 in

winds with westerly velocity components of up to 15 knots (later on, following another assessment by the writer in 1971, up to 20 knots).

In accordance with a revised "*counterclockwise*" Bay TRACON pattern of departure paths, developed and proposed by the writer between July 1968 and August 1969, southbound and southeastbound departures depart from Runway 01-Left, that is, facing north, make a 20° turn to the left as soon as practicable, then proceed over the waters of the Bay for approximately 4 n.mi., and initiate a left turn to cross the Peninsula. Virtually all of the climbs followed essentially the NWA-ALPA procedure and crossed the Brisbane at 4,000 feet altitude and airspeeds of 215 to 220 knots.

Fig.7. Departure paths from San Francisco International Airport, where noise-abatement climb procedures with deep thrust cutback can afford noise abatement to fish, but increase en route climb noise for humans.

For 18 years all was peace and tranquillity, until in the spring of 1987 one air carrier adopted an "*Orange-County*"-like departure procedure with a sharp cutback of thrust shortly after liftoff. With a climb gradient and airspeed acceleration severely impaired, the aircraft followed the standard flight track and crossed into Brisbane at an observed altitude of approximately 2,700 feet and an airspeed of approximately 185 knots. Shortly thereafter, upon attaining an altitude of 3,000 feet almost directly above the residential hillslope area of Brisbane (point "B" in Fig. 7), the pilots, most of whom were not in accord with the entire "*noise-abatement for the fish*" procedure and concerned over their ability to meet a minimum-altitude restriction at the PORTE and PESCA Intersections along the coast, would increase EPR sharply to establish maximum climb power.

The result was easy to foresee, namely, a popular uprising by the people of Brisbane. Only the resolute intervention of the Airports Director and the Mayor of San Francisco dislodged the carrier from its insistence on its "*new national noise-abatement procedure*." Directly upon abandonment of the hapless procedure, the noise-complaint rate from citizens of Brisbane decreased from an average of 60 per day to an average of 2 per day.

(2) In rising terrain, any thrust cutback may only intensify and extend the impact of en route climb noise.

Underneath the climbpath originating from SFO Runways 28, the noise immission over the densely populated upslope terrain toward the San Bruno Gap depends on wind conditions.

In a strong westerly wind, the steep climbpath of departing aircraft minimizes the noise impact of the aircraft in any event.

When westerly or southwesterly winds are weak, departures from Runways 28 of the heaviest aircraft, for which Runways 01 are too short, create a serious noise problem.

So long as the climbout was generally performed according to the NWA-ALPA procedure, all went reasonably well. The "*New FAA procedure*," however, embodies not only an airspeed acceleration, but also a substantial

thrust cutback, even on aircraft with high-bypass ratio engines.

Now (Figs. 7 and 8) heavy aircraft remain closer to the rising terrain until, at 3,000 feet altitude, the restoration of full climb thrust results in an *"outer noise island"* of high single-event exposure levels in the en route climb comparable to those in immediate proximity to the Airport.

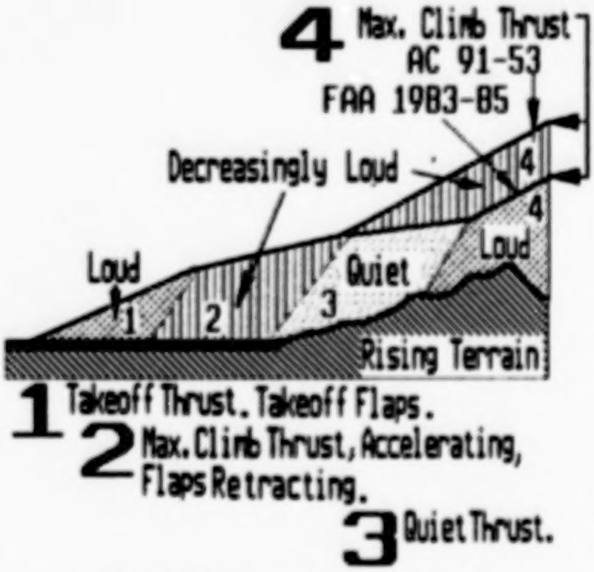


Fig. 8. Climb over Rising Terrain.

A combination of the Brisbane and San Bruno Gap situations obtains also over hilly residential areas of the City of San Francisco, which Runway-01 departures must overfly at a low above-ground altitude and low airspeed following the ill-conceived *"noise-abatement climb"* over the waters of the Bay.

Another comparable en route-climb situation is created by a persistence on the *"noise-abatement climb"* across the Bay of eastbound and northbound departures from SFO Runway 01R, which causes many aircraft to cross the eastern shoreline of the Bay and the residential areas along the slopes of the Oakland Hills at unnecessarily low altitudes.

No longer can most aircraft departing from San Francisco cross the OAK VOR at an altitude in excess of 4,000 feet as formerly. Hence, the procedure creates violations of the OAK ARSA to the embarrassment of those concerned with flight safety and air traffic control.

To What Extent Can Noise-Abatement Climb Procedures Be Standardized?

Limits of standardization.

Standardization of cockpit procedures is mandatory in the interest of safety, but it, too, has a limit when a procedure is counterproductive. The writer has heard more than once from highly conservative pilots: *"Don't they know we have some grey matter between our ears?"*

Takeoff procedures are conducted pursuant to a standard takeoff plate, not according to a single configuration/EPR standard. Noise-abatement procedures, to the extent that they are essential, can also be conducted pursuant to a *"takeoff-climb plate."*

A noise-increasing procedure cannot be a standard noise-abatement procedure.

A so-called *"noise-abatement procedure"* which increases the noise impact either within the area covered by the takeoff climb or in adjacent en route climb areas significantly, should not be practiced with a disregard of local circumstances.

Optimal Standardization of Noise-Abatement Climb Procedures.

A proposal is made to (1) the national air-traffic control systems, (2) the International Air Transport Association (IATA), and (3) the International Air Line Pilots Association (IALPA) to adopt a pair of generalized *"standard noise-abatement climb procedures"* and, for a few airports impacted by noise-sensitive neighbors at the very end of a takeoff runway, a *"desperation standard,"* all three of which should be available to pilots by means of clearly readable *"climb plates"* similar to existing takeoff and landing-approach plates.

The two generalized "*standard noise-abatement climb procedures*" should comprise:

- (1) the FAA/ATA AC 91-53 Procedure with its transition from takeoff EPR to maximum climb EPR at approximately 1,000 feet altitude, thereby reducing the en route climb noise for areas beyond about 6 n.mi. from start of roll
- (2) the "*new FAA procedure*," with its reduction to "*quiet EPR*" upon attainment of V_{ZF} and up to 3,000 feet, which affords noise abatement in areas between 3 and 6 n.mi from start of roll, but at a penalty in en route climb noise.

The "*desperation standard*," which involves a climb from minimum altitude to a specified thrust-restoration altitude with takeoff flaps and "*quiet EPR*" might be a last-resort procedure at a few exceptionally noise-impacted airports, but should under no circumstances be practiced systemwide, where at many airports the substantial loss in total energy of the aircraft is reflected in a heavy subsequent en route noise impact on areas at and beyond the climb-EPR restoration point. The "*desperation standard*" is not favored by pilots for obvious reasons of flight safety.

The foregoing proposal is made with due consideration of the effect of an initial noise-abatement takeoff climb on both the immediate environs of an airport and on more remote noise-sensitive areas subjected to the noise impact of an en route climb that is adversely affected by the curtailment of the total energy of the aircraft in the course of its initial takeoff climb.

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Agenda Toward the Development of a Rational Noise Descriptor System Relevant to Human Annoyance by En Route Aircraft Noise.

Maurice A. Garbell
M.A.G. Consultants, Inc.
San Francisco, California.

Introduction.

A rational, internationally consistent, noise descriptor system is needed to express existing and predicted en route aircraft noise levels in terms closely correlated to the annoyance perceived by people and physiologically identifiable in people, to provide guidance for

- aircraft and powerplant design,
- flight management,
- land-use planning, and
- building codes.

Expanding on previous discussions (Refs. 1, 2, 3, and 4), the present paper seeks to provide a new comprehensive statement of the specific questions that must be resolved by needed research, and the nature and quality of proof that must be adduced to justify further steps toward the drafting and adoption of new international en-route aircraft-noise standards.

The single noise-descriptor system envisioned must be valid for widely varying aircraft-noise frequency spectra, including time-variant components and "*agreeable*" and "*disagreeable*" discrete tones and combinations of tones.

The measures and criteria established by the system must be valid

- at high and low immission levels,
- at high and low ambient noise levels,
- for great and small numbers of noise events, and
- outdoors and indoors.

Historical Background.

Some of the objectives traced herein have attracted numerous individual scientific cause-and-effect, statistical, socio-economic, and legal investigations to date.

Yet, there has not been any coordinated international effort to translate the results of inidividual scientific investigation into a single internationally standardized aircraft noise descriptor system, the need for which is especially urgent for en route aircraft noise which can and does span international boundaries.

Governmental regulatory systems in various countries have formalized diverse "*frozen*" conceptual schemes which have served as the basis for decisions that have affected property rights and the quality of life of humans and animals.

In seeking to develop an advanced aircraft-noise descriptor system, it must be borne in mind that decisions made in accordance with existing government regulations and pursuant to forensice adjudications based on reliance on existing formally adopted descriptors have established formidable precedents that may not readily yield to new definitions, rules, and decisions.

Hence, the proof advanced for any new proposals must be rational and persuasive in light of human experience.

Aircraft noise, in the past and at this time, has been measured and assessed in terms of

(1) the maximum sound-pressure level and/or the total-energy noise-exposure level of a single event,

(2) the equivalent noise level over a stated period of time (for example, one hour), and

(3) the equivalent noise level (L_{eq}) over an entire circadian (24-hour) period, weighted by day and night penalties (L_{dn}) or day-evening-night penalties (CNEL), with sound-level weight factors that are related to periods of human recreation and rest.

Investigations by E.-A. Müller, K.Matschat, and U. Isermann have shown a high degree of correlation between various measures of such types for many aircraft-noise configurations in the environs of a busy airport. Yet, there remains an element of human differentiation between situations in which a numerical value of the circadian L_{eq} might vary little, but in which some specifics of the aircraft noise and the spatial and timewise variation of its characteristics may convey a different message to the affected citizen.

Numerous research undertakings on airport-related noise descriptors have been performed and reported in recent literature. Relatively little has been done with specific application to en-route aircraft noise, the importance of which, long disregarded, is now becoming apparent.

Thus, there still remains a need for a coordinated effort to establish specific goals for studies, criteria for the nature and quality of verification and proof, and assessments of the problems to be overcome in the use of the results of research for administrative implementation. From the outset, a survey of existing administrative aircraft-noise criteria applicable to the impact on humans and animals by en route aircraft noise in various countries is advisable; such survey should reveal not only the criteria that different countries are actually implementing, such as was done in Ref. 5, but the reasons adduced for such implementation and the scope of current pertinent research efforts.

Definition of the Term "En Route" in "En Route Aircraft Noise."

The current FAA-NASA Symposium affords perhaps the first opportunity for scientists, technicians, and regulators to examine the problem of en route aircraft noise in a formal, dedicated, setting.

Whereas the general meaning of the term "*en route*" might be intuitively understood, it is suggested that a precise formal definition of the term "*en route*" would be opportune from the outset, especially since the scientific and technical investigation of the problem of noise immissions on the ground from aircraft in flight away from the airspace of an airport may conceivably lead to administrative, regulatory, and legal consequences that would mandatorily require a precise definition of the term "*en route*."

That definition, for pragmatic reasons, should afford a precise differentiation of the various segments of en route flight in which noise emissions at the source and noise immissions on the ground, are variously affected by airframe configuration, airspeed, powerplant operation, aircraft trjectory, and atmospheric transmission, refraction, and absorption.

A pertinent definition of the term "en route" is proposed in Ref. 6.

Research Goals and Quality of Proof.

The following specific aircraft-noise-related elements relating to en route aircraft noise require clarification at this time:

1. Shall sound-pressure levels or sound-power levels be employed and stated?

2. Is any single schematically ("linear," "A," "C," etc.) weighted sound-pressure level adequate to represent degrees of human annoyance at various numerical levels (Ref. 7), for noises comprising different frequency distribution,

for noises comprising one or more discrete intrusive tonal frequencies, and for noises subject to short-period or long-period fluctuations, all at high and low ambient noise levels?

3. Is it legitimate to attach "*patches*" to schematically weighted sound-pressure levels to account for varying frequency distributions and inclusion of one or more intrusive tonal frequencies and time fluctuations?

4. Can integrative single-event noise exposure values (SEL/SENEL) based on an A-weighted sound-pressure level be "*patched*" to allow for annoyances generated by varying frequency spectra by using "*effective*" threshold-exceedance durations as a form of energy corrections for aircraft noises incorporating intense low-frequency components?

5. Should aircraft-noise assessment be based on, or at least include, a measure that evaluates the entire frequency spectrum, duration and time-variancy elements, of single noise events? Can "*loudness*," expressed in sones (Refs. 7, 8, 9) serve as such a universal measure? Can such a measure be correlated reliably with the magnitude of the EPNL employed in aircraft certification (Ref. 10)?

6. Can meaningful expressions for circadian "*effective cumulative average*" noise levels be derived from the measure of single-event "*loudness*" and "*effective perceived noise level*"?

7. What "time-of-day" allowance or weight should be given to single-event noise levels or hourly or circadian "effective cumulative average" noise levels? After careful consideration, the State of California (Ref. 11) is currently renewing its preference for a "*weight-three*" assessment of noise events during the evening hours (1900-2200 local time), a decision that may create problems on a federal level through its inconsistency with the federally endorsed omission of any evening weight in many of its administrative and financial decisions affecting properties located near airports. Concurrently, the Danish parliament has adopted the same "*evening*" weight of "*three*" for administrative and financial decisions in areas adjacent to airports (Ref. 12). Both Denmark and California continue to use a tenfold weight for nighttime noise events. In addition to the problem of the "*evening*" weight, two questions remain to be answered:

(7-a) Are identical weights to be used for all nighttime hours (2200-0700 local time)?

(7-b) Should identical weights be applied regardless of the magnitude and duration of the exceedance of single-event noise levels over the ambient noise level?

8. Going beyond the concept set forth in Appendix D of Ref. 13 and in Ref. 14, the State of California has experimented with a form of "*normalization*" of observed single-noise-event noise levels and circadian CNELs with reference to the prevailing ambient noise level (Ref. 15). Such reasonings may be of even greater significance in assessing human annoyance over en route aircraft noise in otherwise quiet areas than in urban areas directly adjacent of airports. It is possible, in this respect, that substantial differences in the criteria might arise in different societal cultures?

9. Can a single tolerable limit for a cumulative noise-exposure level be established for single noise events with differing frequency distributions and time-variance characteristics? Can such cumulative noise levels be generalized to a circadian 24-hour time period?

10. How is the tolerable maximum value of the cumulative circadian noise-exposure level of en-route aircraft noise events affected by the otherwise prevailing ambient background level?

11. Can that tolerable value be stated validly for the outdoor ambient alone, or should it apply to the noise immission at a person's ear during a day of activities partly outdoors, partly indoors? It is not clear, from the contents of

Ref. 13 and the recollection of its co-authors, whether the "*tolerable*" Ldn of 55 dB was referred to an exterior or an "*at the recipient's ear*" noise level.

12. What is the maximum tolerable single-event value of the selected form of aircraft noise descriptor? What is the smallest number of such "*dominant*" noise-descriptor levels at which the single-event noise levels and not the time-averaged "*equivalent*" noise level is representative of the annoyance perceived? (See also Ref. 16.)

13. For numbers of noise events at which the time-averaged "*equivalent*" value is deemed to be representative of annoyance, what is an appropriate "*noise-equivalence*" factor for the relationship between the number of events observed and the "*equivalent noise level*"? It has been observed that a 3-dB increase in actual maximum single-event noise levels and single-event noise-exposure levels is barely perceived by most observers, whereas a doubling in the number of dominant noise events is perceived and complained about by many people as "*twice-as-much noise*."

Usage in the United States and many other countries relies on a 3-dB increase in Leq, that is, ten times the decimal logarithm of two for a doubling of the number of dominant noise events. The Federal Republic of Germany has experimented with a 4-dB increment for a doubling of the number of dominant noise events.

The "*number-equivalence*" factor in terms of dB should be re-examined as a function of its pertinence to the degree of human annoyance, especially with reference to en-route noise events of relatively extremely long duration.

14. How can an "*agreeable*" or "*acceptable*" discrete-frequency (or narrow-band) sounds be defined? What is the exceedance level of such discrete tones over the level of an otherwise continuous frequency spectrum or a disagreeably perceived conglomerate of droning or rattling sound, at which even an individually "*acceptable*" discrete tone is perceived as "*disagreeable*" or "*unacceptable*" Ref. 17)?

Here it should be noted that atmospheric attenuation of low-frequency noise is relatively tenuous, so that sound levels are relatively little reduced by increases in flight levels.

17. How can "*agreeable-acceptable*" and "*disagreeable-unacceptable*" dual or multiple tones be defined, especially with reference to the arising of beat frequencies therefrom?

18. In light of the impaired acoustical isolation properties of ordinary construction materials, especially for residential dwellings, against low-frequency noise components, can practicable specifications for such construction materials be established for habitable areas exposed to en route noise immissions embodying different and time-variable frequency spectra?

19. Can frequency and measurable noise-level criteria be established for the acceptability of secondary noise emissions in dwellings that are excited by exterior noise immissions? Can construction criteria be developed to provide for the avoidance of such objectionable interior secondary noise emissions?

20. Can analytical and projective methods be developed to assess and predict the effects of topography, such as valleys and planar and amphitheater-like configurations of hill slopes on the intensification, repetitive immission, and duration of en route aircraft noise events?

21. What is an adequate specification for the level of proof required to test the validity of a newly established aircraft noise descriptor system both with reference to an existing noise situation and for the prediction of a planned, but not yet existing noise situation? How can the quantitative meaning of a representative standard aircraft noise descriptor system be expressed in terms understandable to an intelligent, but not scientifically specialized, layman?

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Additive Evaluation Criteria for Aircraft Noise

Thomas J. Meyer
Hamburg, Federal Republic of Germany

Impact of Outstanding Single Noise Events.

In practice, the occurrence of unexpected aircraft noise events will frequently evoke intense complaints about annoyance over such events.

The *"unexpected"* nature of such events might comprise especially sharply increased maximal sound-pressure levels. Thus complaints arise invariably when previously unknown, noisier, aircraft types appear, or when unusually shallow takeoff-climb profiles are practiced by otherwise well-known aircraft at extremely high takeoff gross weight, or when a change in flightpaths decreases the distance between emissive source and immissive receptor.

The differences between the newly perceived and complained-about maximal noise levels and the previously customary average value pf maximal noise levels are in general markedly greater than their influence on the equivalent noise level, L_{eq}.

No wonder, therefore, that there is a growing body of observations that the equivalent noise level Leq and the evaluation criteria derived therefrom are no longer the sole acceptable and adequate descriptors of aircraft noise in terms of human annoyance (Refs. 1, 2, 3)..

It is recognized that the relationship between the volume of complaints and the corresponding maximum noise levels does in fact depend on the circumstances of the complainants and the time of year. In summertime, when windows are generally held open, even an unexpected noise level in excess of as little as 75 dB(A) can occasion complaints. If exterior noise levels exceed 90 dB(A) without any mitigating factors, massive reactions by the populace affected should be anticipated.

Frequency of Occurrence of Outstanding Single Noise Events.

The frequency of occurrence of the respective noise events is also a factor. Admittedly there is an effect of adaptation. Unquestionably, a single daily event with a maximum noise level in excess of 100 dB(A} will initially give rise to a substantial annoyance. In the longer run, assuming that the unavoidability of such an event is taken into account, such an event will, however, find acquiescence. In this connection one may frequently hear the opinion that 15 to 20 annoying noise events per day can be tolerated, implying that people can adapt themselves to such events, even if initially they had been regarded as *"unexpected"* and objectionable.

An Assessment Criterion.

If these premises are accepted, then one may consider the possible practical value of the addition of the maximal noise level, subject to an as yet to be specified factor, to the well-known cumulative noise descriptors L_{eq}, L_{dn}, etc. One might start by considering the difference between the L_{eq} and the average maximal noise level of the twenty loudest single noise events on an average day. Here, as is well known, the average maximal noise level is determined from the expression

If that difference exceeds 20 dB(A), then even

$$L_{\overline{max}} = 10 \cdot \log \frac{1}{N} \sum_{i=1}^{N} 10^{L_i/10} \, dB(A)$$

with a low L_{eq} and correspondingly high maximum noise levels massive complaints should be anticipated. A somewhat less sharply focused

consideration of the maximum noise levels was adopted in the recent revision of a German standard noise-mitigation standard (Ref. 4). In that standard the scope of noise-mitigation measures is defined generally with reference to L_{eq}, as is the international custom. If the average maximal noise level $\overline{L_{max}}$ of the *entire* aircraft fleet mix, that is, not only that of the noisiest class of aircraft, exceeds the L_{eq} by more than 20 dB(A) and if, concurrently, more than 20 daily aircraft noise events exceed the L_{eq} by more than that noise-level difference, then the difference $\overline{L_{max}}$ - 20 becomes the key criterion for noise-mitigation measures.

Do Quieter New Stage-III Aircraft Abate Annoyance Over Residual Noisy Aircraft?

It might be significant that an increasing participation of quieter aircraft in the aircraft fleet mix, for example, ICAO Annex 16, Chapter 3 (FAR-36, Stage III) air-craft, may depress the value of $\overline{L_{max}}$. Inasmuch as the number of Chapter-2 (Stage-II) aircraft is diminishing with time, but their participation may still exceed a daily number of 20 operations at a major airport, there is no assurance that a decrease in the $\overline{L_{max}}$ of the overall aircraft fleet mix can achieve a proportional decrease of the total annoyance.

Assessment Procedure.

A forecast of the numerical occurrence of the anticipated maximal noise levels without pre-existing noise-level measurements requires a knowledge of the scatter distribution of that level above and below the corresponding average maximal noise level. A statistical correlation of a large number of data from aircraft-noise-monitoring sensors located at various distances both directly underneath and laterally disposed relative to an aircraft flight-path has in fact supplied a basis for the determination of the distribution of the maximal noise levels about the average value, $\overline{L_{max}}$, of each type of aircraft reflected in Fig. 1. This distribution is given both for the takeoff climb and for the landing approach.

The foregoing procedure, it is evident, applies only if a single flight track or flyway is found to govern the immission levels. Should several different flight tracks, flyways, or runways participate in creating the noise-immission impact, then the immission levels must be determined separately for each flight track, and the respective frequencies must then be summated. The same applies to separate aircraft types with differing noise-emission characteristics. The legend for Fig. 1 supplies a key for a corresponding calculation scheme.

At all monitoring locations investigated to date, the deviation of the locally determined values of $\overline{L_{max}}$ was found to be less than ±1 dB(A). Deviations of less than 1 dB(A) are generally disregarded. The frequency distribution appearing in Fig. 1 can be employed also in those cases when deviations from calculated statistically averaged immission levels, attributed to exceptional local conditions, are known to exist.

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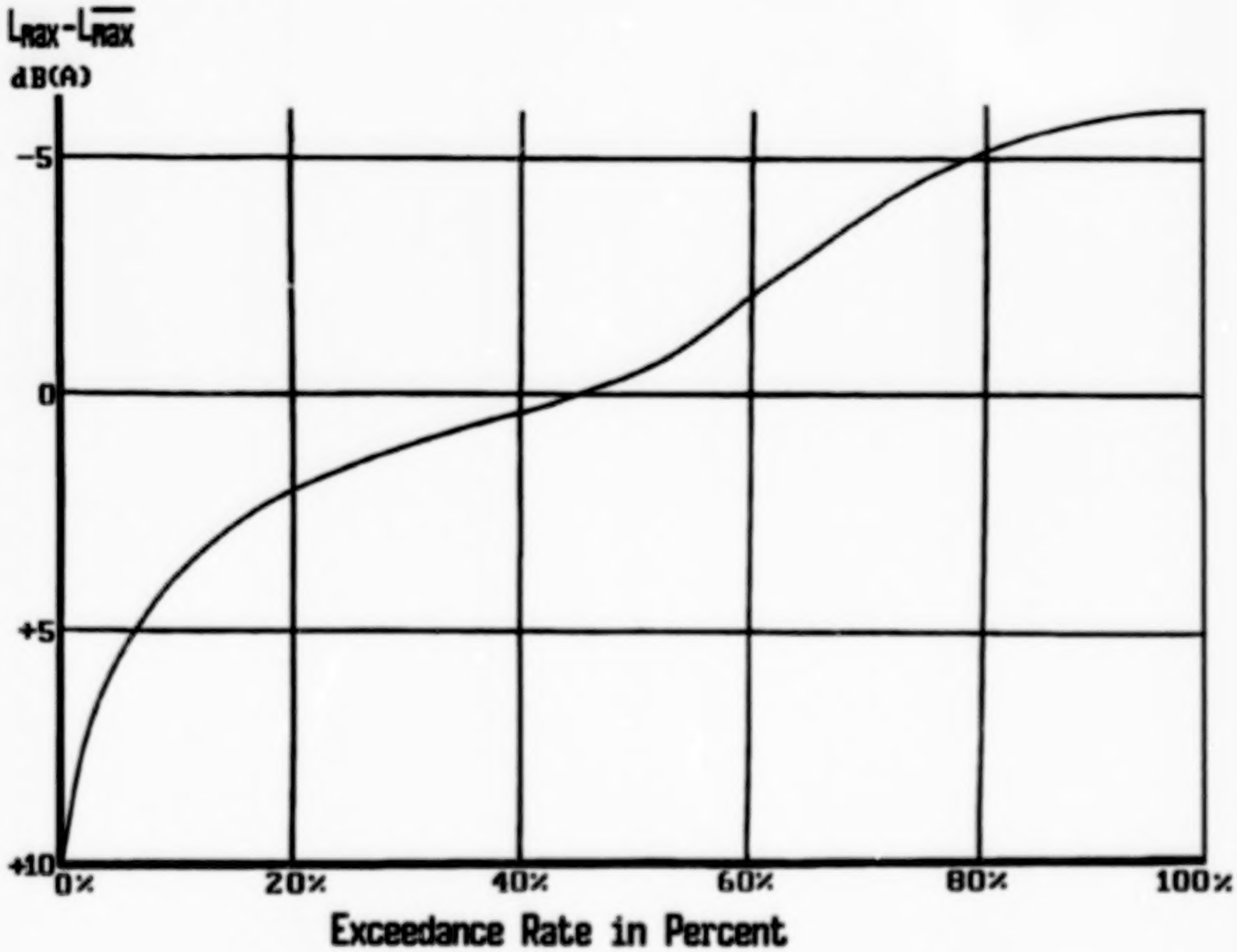

Fig. 1. The Likelihood of Deviation of a Specified L_{max} from a Logarithmically Averaged $\overline{L_{max}}$.

Example A. If $\overline{L_{max}}$ of aircraft type X_1 at immission location Y underneath a given flight track is 85 dBA, what is the exceedance rate for a L_{max} = 90 dBA of that type of aircraft at that location underneath the same flight track? L_{max}-$\overline{L_{max}}$ = + 5 dBA. The diagram yields an exceedance rate of 6% of all aircraft of the type X_1 for that location underneath the same flight track.

Example B. If $\overline{L_{max}}$ of aircraft type X_2 at the same immission location Y underneath the same flight track is 92 dBA, the diagram yields for the exceedance rate for L_{max} = 90 dBA, that is, for the case of L_{max}-$\overline{L_{max}}$ = -2 dBA a value of 59% of the total number of operations.

Summation. The absolute exceedance numbers for both types of aircraft must then be added to determine the total number of L_{max} exceedance events above 90 dBA.

SOCIAL SURVEY FINDINGS ON EN ROUTE NOISE ANNOYANCE ISSUES

James M. Fields
Silver Spring, Maryland

Most surveys of residents' reactions to aircraft noise have been conducted in the vicinity of airports. The findings in those surveys have supported planning and regulatory actions for the airport noise environment. Now, however, aircraft noise planning and regulations are being considered for a new environment, the en route environment. As policy makers search for bases for public policy in these new noise environments, it is appropriate to ask whether the same scientific evidence which supports airport noise policy can also support en route noise policy. This paper considers several aspects of that question.

The paper is divided into four sections. An introduction establishes the scope of the present study and examines alternative study methodologies. Next, the selected study methodology is described and important assumptions are listed. The body of the paper then consists of the findings on en route issues. The final section presents findings on relevant research methods and considers priorities for further research.

Introduction

Final study methodology

Findings about en route/airport differences

Methods and priorities for further research

Introduction: En Route Aircraft Noise Surveys

What type of methodology should be selected to provide information about en route noise reactions? An obvious approach is to examine any previous surveys of reactions to en route aircraft noise. Ten en route noise surveys have been identified and are listed in Table 1. Eight surveys studied reactions to sonic booms, one studied low altitude military flights and one studied helicopter flights. Each of the surveys found some annoyance with en route noise. None of the surveys is very useful for isolating the effects of the en route setting because any en route effects are confounded with the effects of the unusual noise sources studied. The only possible exception, the British Helicopter survey, was designed to be compared to previous fixed wing aircraft surveys in the vicinity of airports. This survey could not precisely estimate the noise/annoyance relationship because of the small number of study areas (six) and large differences between the reactions of the study areas. The survey did not find a systematic difference between reactions in previous surveys and those in the six study areas.

Survey	Noise source
1961 St Louis Sonic Boom[1]	
1964 Oklahoma City Sonic Boom[2]	
1967 SR-71 Supersonic Aircraft[3]	
1965 Regional French Sonic Boom[4]	Sonic Boom
1970 French Sonic Boom[5]	
1971 French Concorde[6]	
1969 Meppen Sonic Boom Field Experiment[7]	
1972 Burgsvik Sweden Sonic Boom[8]	
1986 Netherlands Low Altitude Military[9]	Low Altitude Military
1982 British Helicopter Disturbance[10]	Helicopter

Table 1: Ten surveys of en route aircraft noise (N=18,380)

The examination of these en route surveys has helped to clarify the objectives for the present study. The objective for this study is to understand how noise annoyance is affected by differences between the en route and airport noise environments. Other studies, including laboratory studies, are needed to understand how noise annoyance is affected by differences in noise sources. Such studies compare the reactions to the noise of conventional aircraft and the noise from supersonic aircraft, propfan propulsion systems, low altitude military aircraft or any other noises which may dominate a specific en route noise environment. The objective of the present study is not to estimate a specific level of annoyance but rather to determine whether there is a difference in reactions between the en route and the airport environments.

The approach to this objective cannot be a simple comparison of existing en route and airport environment social surveys. The required approach is a more analytical approach in which the critical components of the en route environment are identified and expressed as hypotheses which can be individually tested under the range of conditions which are present in existing noise environments.

Study Objective

Compare expected en route/airport noise reactions
- Not Examine effect of specific noises
- Not Estimate absolute levels or reactions

Approach

Identify en route characteristics and test in existing environments

Not Contrast en route/airport surveys

Introduction En Route Hypotheses

Eight hypotheses have been identified which provide the bases for speculations that reactions to en route and airport noise environments will differ. These eight component hypotheses can be grouped under three headings.

Four hypotheses suggest that the presence or absence of an airport can effect reactions. Residents who are distant from an airport may be more annoyed because they would not directly benefit either through employment or usage from an airport's presence. It is hypothesized that annoyance is reduced if benefits are received from the noise source. The distant en route population could be expected to be more noise-sensitive generally, if the obvious presence of an airport has, over a period of time, served to create a self-selected population of airport residents who are relatively insensitive to noise. It is hypothesized that people at low noise levels are more sensitive to noise generally, regardless of the source. En route residents may also be differentially affected because aircraft are not engaged in conventional landing and take-off operations. It is hypothesized that annoyance is increased by exposure to non-noise problems from the noise source. It is also hypothesized that annoyance is increased if fear is associated with the noise source. The non-noise impact and fear hypotheses have different implications for low and high altitude aircraft. For high altitude aircraft, such as the propfan, en route residents may be less annoyed by the noise because they do not experience some of the non-noise problems associated with being near the source such as air pollution, dirt, lights or the visual presence of aircraft. They also may be less annoyed because they are less fearful of danger from an aircraft crash. For low altitude military training routes, on the other hand, en route residents may be more annoyed if they experience greater fear or other non-noise problems which could increase noise annoyance.

The en route noise environment differs in two additional respects. In contrast to the typical high ambient noise, urban setting around airports, there may be low ambient, rural or suburban settings at many en route noise locations. It is hypothesized that low ambient noise levels will heighten the reactions to any intruding noise. Much of the en route population could also be exposed to quite low aircraft noise levels; well below the typical 55 or 65 L_{dn} noise standards for aircraft noise which are often regarded as levels of minimum impact around airports.

Finally, some of the greatest attention is focused on a changing situation in which there is an introduction of a different or louder noise. It is hypothesized that there will be more annoyance with a changed noise environment than with a steady-state condition. It is also hypothesized that people adapt to new noise environments so that such a heightened reaction would be temporary.

Hypotheses

Hypothesis	En route noise annoyance is Less	Greater	Same
Airport /no airport			
Less benefit		H	
Non-noise problems*	H(HA)	H(LA)	
Fear /danger*	H(HA)	H(LA)	
Noise sensitivity (general)		H	
En route noise setting			
Low ambient noise		H	
Low (<55 Ldn) source noise*	H(HA)		
Change in noise			
Change in source noise		H	
Adaptation to change			H

* (Opposite predictions for High (HA) and Low (LA) altitude en route noise)

How might these eight hypotheses best be examined? Three strategies were considered but rejected. Conducting a new social survey was rejected because more information is readily available from previous surveys than could be collected in one additional survey. A secondary analysis was considered in which the original, individual respondents' data in previous surveys would have been reanalyzed using a common methodology. A secondary analysis was rejected at this stage because all surveys, not just those with readily available data sets, need to be evaluated. A standard qualitative literature review was also considered but rejected. As has been observed for other areas of social science research..."Contemporary research reviewing should be more technical and statistical than it is narrative...The findings of multiple studies should be regarded as a complex data set, no more comprehensible without statistical analysis than would hundreds of data points in one study."[11]

The selected approach is to conduct a quantitative analysis of existing findings. Techniques for the statistical analysis of study findings have been developed under the general heading of "Meta-analysis".[12,13,14] The specific techniques can not be directly applied in summarizing results of environment noise surveys because these surveys do not use standard measurements of independent variables, do not use similar descriptive statistics and usually do not take into account the clustered sample designs in calculating inferential statistics. The meta-analysis literature does, however, set three general requirements which are applicable to the present analysis. A satisfactory quantitative analysis draws on an all-inclusive inventory of surveys, objectively documents the study methods and quantifies the findings with a suitable statistic.

New, single social survey

Secondary analysis

Qualitative literature review

Quantitative review of findings (Meta–analysis)

Requirements:

— Inclusive set of past studies

— Objective, documented methods

— Suitable summary statistic

Methodology — Major Steps in the Methodology

The methodology which was finally adopted consists of fifteen steps. First, a major attempt to locate all English language publications describing surveys of residents' reactions to community noise identified 280 surveys of reactions to aircraft, road traffic, railway, industry, and other community noise. Next operational definitions of hypotheses were developed. Next, each of over 640 publications were evaluated to locate findings relating to the hypotheses.

After identifying a potential finding, a twelve-step screening and classification process classified the finding for the analysis. This methodology produced the types of records of findings which are shown in Table 2. Findings were screened out unless the annoyance variable measures the respondent's overall noise annoyance with a specified noise source within the context of the residential environment. The definition of the issue variable ("benefit" in Table 2) had to meet any special conditions related to testing the specified hypothesis. The reported number of respondents is approximate (sometimes only the sample size and not the exact number answering a question is available) and may be less than the total number of completed questionnaires when, as for a panel survey, there are multiple responses.

Once the relevant information was recorded, the finding could be coded by result for the study hypothesis (supporting the hypothesis, supporting an opposing hypothesis or not supporting any effect) and according to the strength of the supporting evidence (standard or weak). Supporting evidence was classified as "standard" if the design or data analysis method included a method for controlling or normalizing for differences in noise level and if one of three selected statistics had been used to measure the size of an effect. (An author's comments on unique survey attributes also occasionally caused a finding to be classified as weak.) It should be noted that the "standard" or "weak" classification considers only the relevance of the evidence for a specific hypothesis and is not a judgment of the overall quality of the survey.

- Identify social surveys (N=280)
- Prepare operational definition of hypotheses
- Examine all documents (N~640)
- Classify findings (12 steps)
    - Establish eligibility (annoyance/variable)
    - Determine results (Support/Against/No)
    - Evaluate support (Standard/Weak)
        - Summary statistic
            - Standard statistic (3dB, 5%, 1%r)
            - Other indicator
        - Control/normalize for noise
        - Other (issue-specific)
    - Determine sample size (Accuracy surogate)

Issue: Benefits (employment, usage)

Hypothesis: Annoyance is reduced by benefits received from the airport or other noise source.

Study (Catalog ID number)	Finding: If benefit, noise annoyance is: Lower	Same	Higher	Methodology: Type of benefit	Variables controlled	Comments	Reference
1975 German General Aviation (GER-114)		X_r ns {1}		Involved professionally with airfield or aircraft	None	r_{ax}=-0.03 [N=398]	Rohrmann, 1975:64
1972 English Road Traffic (UKD-072)		X_* {1}		Car ownership, holding driving licence	Traffic flow (Vehicles per hour)	Only 3% fewer car owners scored high on disturbance. Disturbance is not related to number of vehicles. [N≅5,800]	Morton-Williams, Hedges, Fernando, 1978: 68, 72,88
1980 John Wayne Airport (USA-207)	X_{vb} {4}			Use of airport, weekly, monthly, yearly, other	Noise (All are in 65 CNEL contour)	Users"..are less likely to state that...aircraft noise is a problem for you in your neighborhood.." [N≅300]	VTN Consolidated: X-30
1982 United Kingdom Aircraft Noise Index (UKD-242)	X_* ?s {1}			Work at airport or for company doing business with an airport	Noise (24hr L_{eq}, for 1 week)	It is reported that "in some areas" economic ties are associated with a 25% decrease in rating of "not acceptable" (not individual-level analysis). [N≅2090]	Brooker and Richmond, 1985b:335; Brooker, Critchley, Monkman, Richmond, 1985:4,28, 59,131
1983 Controlled Exposure Helicopter (USA-235)		X_{dB} ns {1}		Household member employed by military	Noise (L_{eq})	A not significant -0.3 dB response reduction for military. [n≅4000 daily interviews by N≅330 respondents]	Fields, Powell, 1987:488; Fields, Powell, 1985,41

Table 2: Example of a findings table (first five findings on benefits hypothesis)

Methodology

A Summary Statistic

The most critical aspect of the study methodology is the determination of whether a finding supports or does not support a hypothesis.

Each finding is classified by whether or not there is evidence of an "important" effect on annoyance where "important" is defined by specific statistical criteria. All statistics do not provide equally relevant evidence and thus a finding is classified by the highest level of evidence available. Six levels of evidence have been identified. One of the first three types of statistics must be available for a finding to be judged as "standard". The highest level of evidence comes from a measure of the decibel equivalent of the annoyance differential produced by a variable. The "important" effect criteria is an effect equivalent to the effect of at least a 3 decibel difference in noise level. A 3 dB equivalent effect favoring a hypothesis is counted as "support" for a hypothesis, a 3 dB effect opposing the hypothesis is counted as supporting the opposite of the hypothesis, and any effect of less than 3 dB is counted as not "important". If information about the decibel equivalent of an effect is not available, then statistics on the percentage differences between subgroups are sought. A 5% difference is defined as an "important" difference. For example, if residents living at an aircraft L_{dn} of 70 are examined and it is found that 25% of those employed by the airport are highly annoyed by aircraft noise but 35% of the remaining population are annoyed, then there is a 10% difference, and it is concluded that the finding should be counted as "important" support for the hypothesis. If evidence on the size of a percentage difference is not available then evidence about the percentage of variance explained is considered. An "important" difference explains at least 1% ($r \geq 0.10$) of the variance. The choices of the 3 dB, 5% and 1% variance criteria are largely arbitrary. Most noise regulations use five-decibel step increments and thus it could be argued that a difference of less than three decibels would be unimportant. The 5% difference is approximately the increase in the percentage "highly" annoyed at about 65 L_{dn} specified by one widely accepted dose-response relationship.[15] The 1% variance explained ($r=0.10$) in individual annoyance scores is a largely arbitrary choice but is very approximately consistent with the other indicators in a few surveys in which it has been examined. For multi-category variables with uneven population distributions there is not a simple invariant relationship between the percent of variance explained and the other criteria.

Weaker evidence on a hypothesis can be provided by the results of a statistical significance test or (if no test is available) other numerical evidence (eg. differences between mean annoyance scores) or (if no other evidence is available) a verbal statement in a publication. Previous studies on meta-analysis methods have firmly established the fact that simple counts of the results of significance tests are very weak evidence and can bias the results of a summary.[16]

After all of the findings on a hypothesis have been classified, a final criterion must be applied to determine whether the combined results support or reject a hypothesis. In this paper a hypothesis is considered to be supported if over 50% of the tabulated findings show an "important" level of support for the hypothesis.

These simple criteria for evaluating hypotheses have the advantages of being unbiased, relatively easy to apply and readily transparent to readers. More powerful statistical methods are available for combining results from studies, but they require assumptions which could be legitimately met for only a small number of noise surveys. The broad scope of this less powerful review serves to identify major findings and, when the complete review is published, will provide a comprehensive listing of sources of information about major noise annoyance hypotheses.

Methodology: Suitable Summary Statistic

Count findings showing "important" impact

- Standard evidence
  - $\geq$ 3dB equivalent response difference
  - $\geq$ 5% difference in % annoyed
  - $\geq$ 1% variance explained
- Weak evidence
  - Significance test (only)
  - Other quantitative
  - Verbal statement (unequivocal)

Criterion to accept hypothesis

- 50%+ of findings support

Results*   Benefits and Non-noise Disadvantages

This study's methodology has been applied to twenty-eight hypotheses about community noise annoyance. Fifteen provided evidence about the en route noise issues, three addressed social survey methods, three addressed additional demographic characteristics and five addressed individual noise exposure hypotheses. Of the 280 surveys examined, 120 surveys provided approximately 400 findings on at least one of the 28 hypotheses.

The first results in Figure 1 address the hypothesis that annoyance is reduced when a resident receives direct benefits from a noise source. The 22% for the first bar shows that of the 18 findings (F=18 findings) which provide evidence on the hypothesis, only 4 (18*0.22=4) indicate there is an "important" effect supporting the hypothesis and none provide "important" support for the opposite hypothesis (ie. that those receiving direct benefits would be more annoyed). Thus 78% of the findings do not provide evidence of an "important" effect. The first bar (solid bar) simply represents a count of all findings but does not consider the differing sample sizes or the relative quality of the findings.

The second bar adjusts for sample sizes and shows that the previously reported 22% of the findings represented 17% of the tabulated interviews. For the "benefit" hypothesis the interviews come from an estimated N=28,453 respondents. The third and fourth bars (left and right diagonal fill patterns) represent only the "standard-evidence" findings. For the benefits hypothesis, for example, only 9 (F=9) of the previously cited 18 findings are based on "standard" evidence. These 9 findings are based on only 12,503 of the 28,453 respondents.

For the benefits hypothesis all four of these summary statistics support a single conclusion: receiving a benefit from the noise source does not reduce annoyance. The best present evidence is thus that a lack of benefits does not affect en route annoyance.

For the second hypothesis addressed in Figure 1, non-noise problem, the evidence comes from five findings drawn from two aircraft surveys[17,18] and one railway survey[19] with 4,500 respondents (the "(3)" following the number of findings indicates that 3 surveys provided the five findings). Non-noise presence is measured by either the respondent's position relative to the flight path or by an independent observer's rating of the visibility of the railway and of the presence in the neighborhood of fumes, dirt or vibration from the railway. Only two findings (3060 respondents) met the standard evidence criteria. The finding from the smaller study supports the hypothesis. Using our 50% criteria (i.e. the shaded area in the figure), the four bars provide some mixed support for the hypothesis that noise reactions are affected by non-noise intrusions from the noise source. The results thus suggest that reactions to high altitude en route aircraft might thus be reduced while reactions to low altitude aircraft might be increased.

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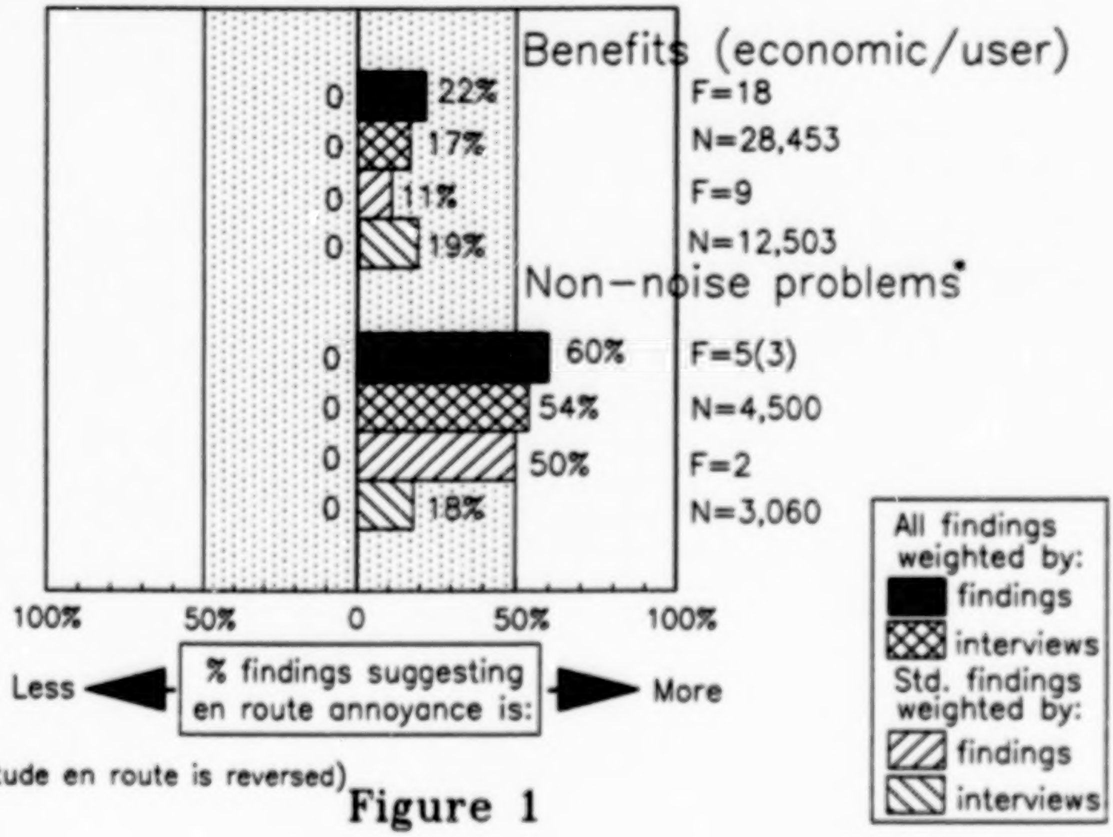
*This section contains figures 1-8.

Findings about benefits and disadvantages from noise source



•(High altitude en route is reversed)

Figure 1

Results Attitudes

Attitudes about non-noise disadvantages of the noise source were examined in two of the previous surveys using respondents' perceptions of aircraft air pollution or, in a railway survey, of railway dirt, smells, lights or invasion of privacy. The results in Figure 2 show that in both surveys respondents' perceptions of non-noise disadvantages are related to increased annoyance. This is thus additional, though weak, attitudinal evidence that annoyance may be increased by non-noise disadvantages.

The effect of fear or danger from the noise source (primarily from crashes for aircraft) has been examined in 20 surveys with 43,244 respondents. Every finding tabulated in Figure 2 shows that increased fear is associated with increased annoyance.

Three of four findings (5,882 respondents) support the hypothesis that noise annoyance is related to perceived importance of the local airport. Presumably attitudes towards any particular en route noise would be related to attitudes about the importance of the particular noise source. It could be speculated that, for example, annoyance with low-flying military aircraft would be reduced for those who believe such flights are important for national defense. While the data can show what variables are associated, any conclusions about the causal implications of such associations are speculative at best. For example, though the attitudinal data in Figure 2 suggest that people who feel the noise source is important will be more annoyed, the factual data on benefits in Figure 1 showed that those people for whom the noise source might actually produce important tangible benefits are not more annoyed.

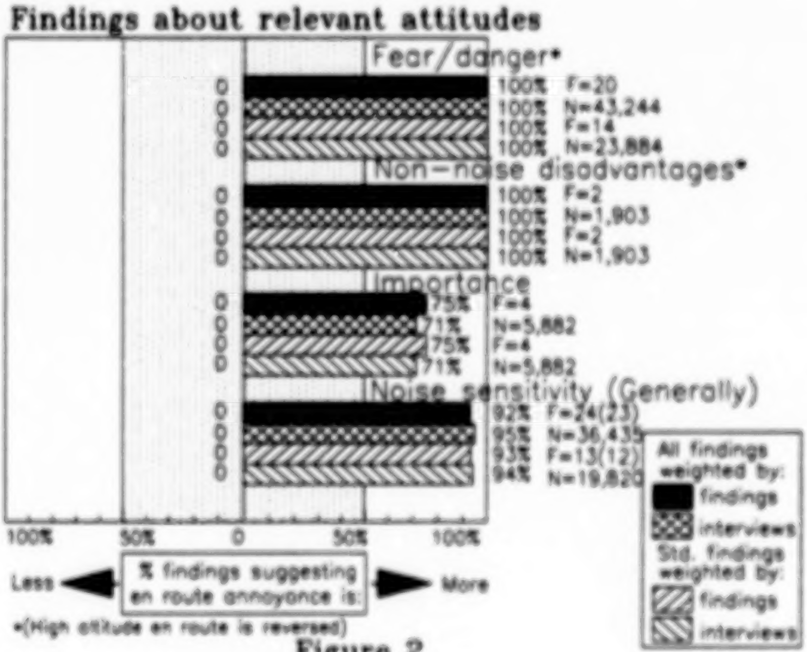


Figure 2

Results   Sensitivity

The data on the last of the four attitudinal issues show that noise annoyance with aircraft is related to general noise sensitivity. Most questionnaires measure noise sensitivity by asking for the respondents' judgments about their own noise sensitivity relative to "most people" or by asking for ratings of annoyance from such common sounds as a banging door, dripping tap, or lawn mower. (For this report's hypothesis some surveys' measures of sensitivity have been excluded because they included references to local environmental noise.) For en route noise evaluation the critical question is whether such general sensitivity is related to the environmental noise level because more sensitive people might avoid high noise areas either by finally moving away or by initially not moving into the high noise airport areas.

In Figure 3 the data from 17 findings (over 30,000 respondents) indicate that there are not consistent, important differences in sensitivity between residents in high and low noise areas. The data from four findings indicate that residents are no more likely to move (or plan to move) from high than from low noise neighborhoods. One attitudinal variable is also reported in Figure 3. It is found that less than half of the five surveys (but representing more than half of the respondents) reported that respondents who are most bothered by the noise are also most likely to report that they plan to move. With such an attitudinal variable it is not clear, however, whether greater annoyance is causing the movement or whether the prospect of moving leads the respondent to a more negative evaluation of all aspects of the neighborhood environment. In either case the evidence for an effect is weak.

The evidence in Figure 3 does not support the hypothesis that general noise sensitivity is related to noise level. Thus the evidence does not suggest that traditionally low noise level areas will contain unusually noise-sensitive populations.

Findings about general noise sensitivty
at high noise levels

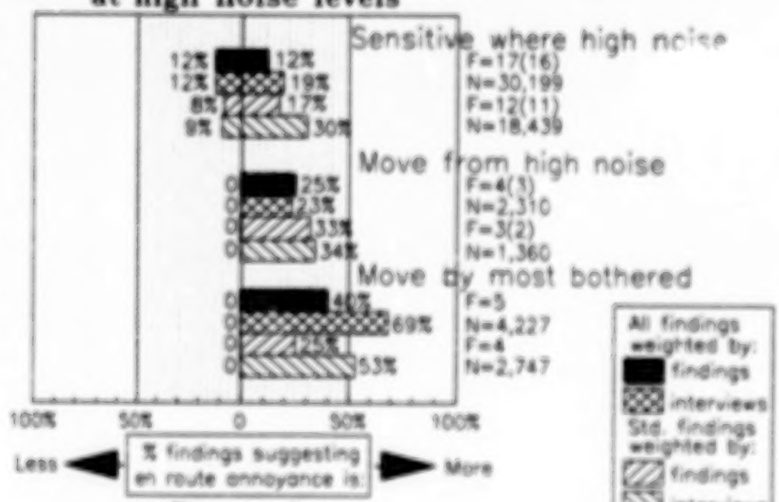


Figure 3

Finding Ambient Noise

It is sometimes assumed that people will be more annoyed if a noise is experienced in the context of a low ambient noise environment. Figure 4 shows that 22 findings from 20 surveys (27,987 respondents) have evaluated the effect of ambient noise level on reactions to noise. Most surveys measured both the rated noise and ambient noise outside the house. The reaction is, as for all other findings, a rating of annoyance with a specific noise source. The data do not support the hypothesis that reactions to noise are affected by ambient noise level.

The survey reports do not directly measure the likelihood of masking of different noise sources. At least some of the surveys include sites with ambient noise levels below 40 L_{eq} and some sites at which the rated noise source is sometimes masked by the ambient noise but sometimes clearly audible. Most of the data, however, probably come from sites where the rated noise source is seldom masked by ambient noise levels outside the home.

Findings about reactions at low ambient noise levels

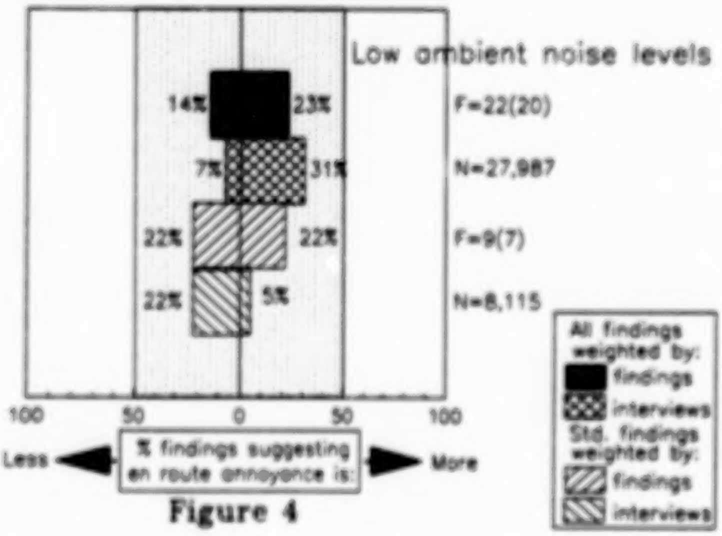
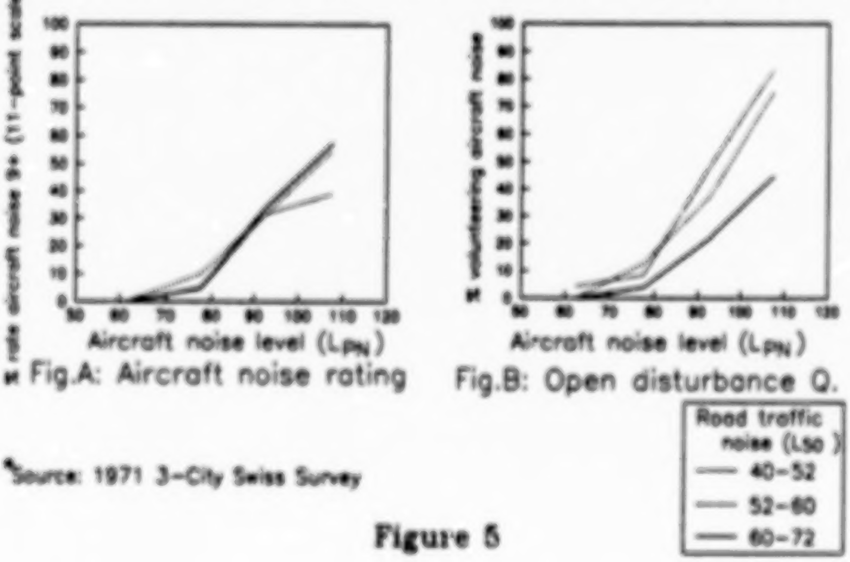


Figure 4

Finding Ambient Noise

Some of the previously published support for an ambient noise hypothesis was examined. In some cases the conclusions are not based on direct ratings of a noise but only on relative rankings of ambient noises and other noise sources. The original report on the well-known 1971 Three City Swiss Noise Survey was examined for this review and it was found that ambient noise added less than one tenth of one percentage point (0.03%) to the explained variance. Figure 5A shows that the ambient noise level did not affect aircraft noise annoyance when measured on an 11-point "thermometer scale". (Aircraft noise level is the logarithmic average peak noise level for aircraft noise events expressed in PNDB.) In a 1978 review Schultz, however, cited the clear relationship with ambient noise in Figure 5B as evidence for an ambient noise effect.[20] This finding in Figure 5B is based on an open question which asked the respondent to volunteer anything in the nearby environment which the respondent disliked. Respondents seldom volunteer more than one or two answers to such a question and thus the question measures the relative salience of aircraft noise rather than the degree of annoyance with aircraft noise. These analyses and those from other surveys[21] show that people's absolute level of annoyance with a noise source is not affected by ambient noise but that the relative ranking of the importance or salience of several noise sources is, of course, affected by the relative noise levels of the sources.

Aircraft noise annoyance at three ambient levels for two indicators of aircraft noise annoyance*



*Source: 1971 3-City Swiss Survey

Figure 5

Most of the noise survey evidence comes from residents at high noise levels. Of the 280 surveys only 16 asked about high annoyance and included respondents at estimated noise levels of 55 L_{dn} or lower. These surveys' findings are tabulated in Figure 6 for 5-decibel groups from 30 to 55 L_{dn}. The first three pairs of bars in Figure 6 show that every one of the surveys which had interviews at the 50-55, 45-49 and 40-44 L_{dn} levels found that some respondents reported high annoyance. Only two surveys provide evidence between 39 and 39 L_{dn}. The 1971 Three City Swiss Noise Survey reported some high annoyance while the British railway survey reported no high annoyance.

Kryter has speculated from extrapolations of survey data that about four to eight percent of the population below 55 L_{dn} may be supersensitive and thus be annoyed regardless of noise level. On this basis it could be argued that at low noise levels the response curve is asymptotic and that further reductions in noise level do not yield further benefits in reduced annoyance. This argument was tested with eight surveys which included data from 55 L_{dn} down to 45 L_{dn} or lower. As the data at the bottom of the figure show, in every case a positive slope relates annoyance to noise level.

The data reviewed in Figure 6 show that there is annoyance for noise sources with day/night levels of less than 55 L_{dn} and that reductions of noise levels below 55 L_{dn} yield benefits in reduced annoyance.

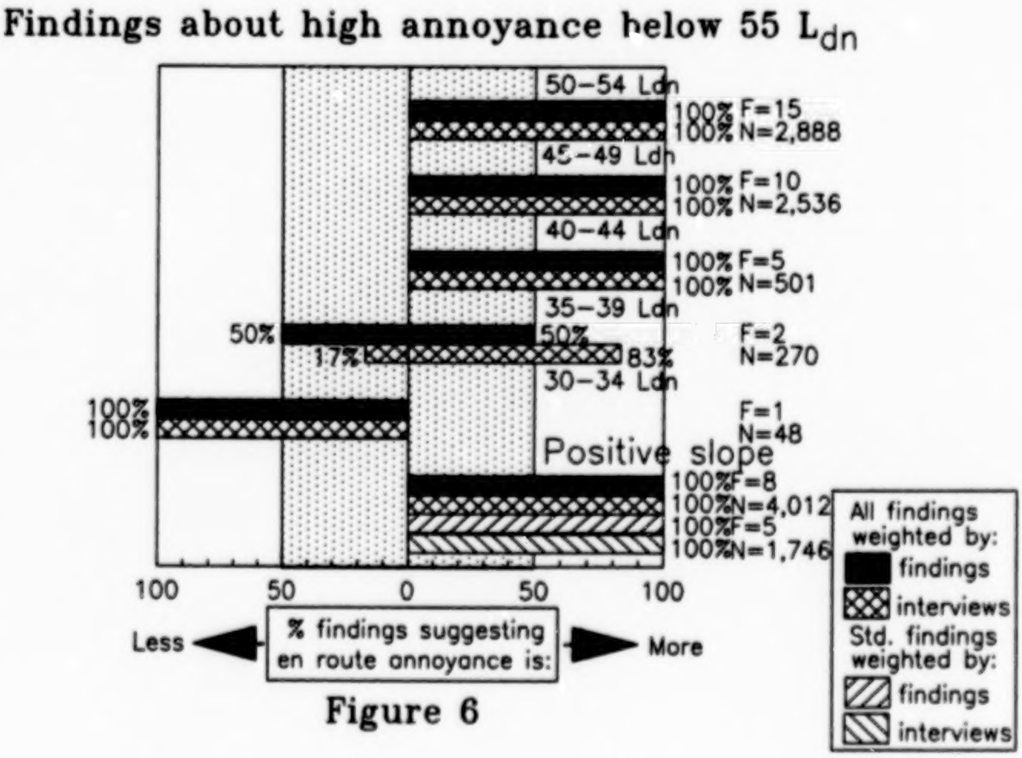


Figure 6

Results Reaction to Change in Noise Level

The first two issues considered in Figure 7 contrast residents whose noise environment has recently changed to a new noise level with residents at the same noise level in other locations whose noise environment is unchanged. An "important" finding is recorded if those in the new noise environment over-reacted by the equivalent of at least 5 decibels compared to those living in the unchanged noise environment. The first 19 findings include both increases in noise levels and decreases in noise levels. The 3 of these 19 findings which come from increases in noise levels are reported separately in the second set of bars. There is not a clear pattern in the findings.

The remaining two issues in Figure 7 address the possibility that people may adapt to new noise environments over time. Seven surveys contrast reactions at two points after an increase in noise has occurred in order to determine if residents adapted. The number of respondents is relatively small and the evidence is again mixed. Though the number of surveys is almost evenly split between those showing adaptation over time and increased annoyance over time, the larger surveys (representing 49% of the respondents) are slightly more likely to show adaptation. The effect of length of residence in relatively stable noise environments is examined with 44 surveys. The evidence does not suggest that people adapt to noise over the time periods studied here.

Most of these surveys first measured respondents' reactions four months to a year after a change in noise environments. The lack of consistent support for the effect of change is thus consistent with the possibility of rapid adaptation in the first days or weeks of exposure.

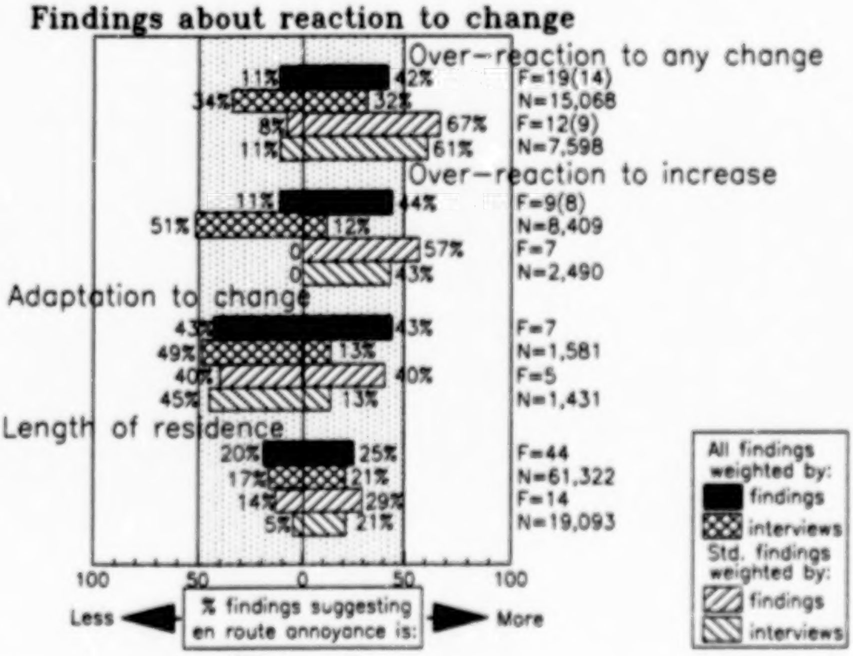


Figure 7

Summary

The results of this study are summarized by returning to the eight original hypotheses. Two reasons remain for believing that some en route noise (only high altitude en route noise) might be less annoying than airport noise of the same noise level: the presumed absence of fear in a high altitude en route setting and the expected absence of any noise-source-related, non-noise problems in a high altitude en route setting. The evidence suggests neither general noise sensitivity, nor an absence of direct benefits, nor reduced ambient noise levels will affect reactions to en route noise. The evidence on changes in noise levels is unclear. The evidence on reactions at low noise levels shows that these surveys found high annoyance in areas which are estimated to have noise levels below 55 L_{dn}.

The methodology reported in this paper has provided an objective and concise review of the evidence on the presence or absence of eight variables' effects on noise annoyance. Further research would be needed to more precisely specify the size of any effects. Two types of methodologies could contribute to further research on these issues: new social surveys of annoyance in community settings and secondary analyses of the primary data sets of previous surveys. Cost is a primary consideration in conducting new surveys. Findings relating to cost-cutting methodologies and to required sample sizes have been examined.

Most previous social surveys of noise annoyance have been conducted with personal, face-to-face interviews, but many survey organizations now rely primarily on less expensive telephone interviews. Figure 8 indicates that four surveys have compared telephone and face-to-face interviewing methods. Only one met the standard evidence criterion, but none of the findings indicated that there was a difference between annoyance levels for telephone and personal interviews.

Probability sampling methods require that the respondent be selected using strictly controlled random selection methods from a list of all household members. Cost savings could be achieved, however, if an interview could be completed with the first individual contacted in a household. This procedure would bias a sample toward people who are often at home and thus are more exposed to the noise. Figure 8 indicates that there is not a clear tendency in the 17 identified surveys for the more often at home respondents to be more annoyed. Two of the four surveys with standard findings did find that those who are home more were less likely to be annoyed. In the 1960's and 1970's when many of these surveys were conducted, women were more likely to be at home. The findings from the 46 surveys in the figure indicate, however, that women are not more annoyed then men. According to the standard 50% criteria, the balance of the evidence suggests that the amount of time at home does not affect reactions. However, the evidence is somewhat mixed. Given the strictness of the probability sampling rules, these are probably not strong enough evidence to abandon the strict standard selection methods for choosing household members. It is possible that a secondary analysis of existing data might provide stronger evidence.

Findings about cost-cutting methodology

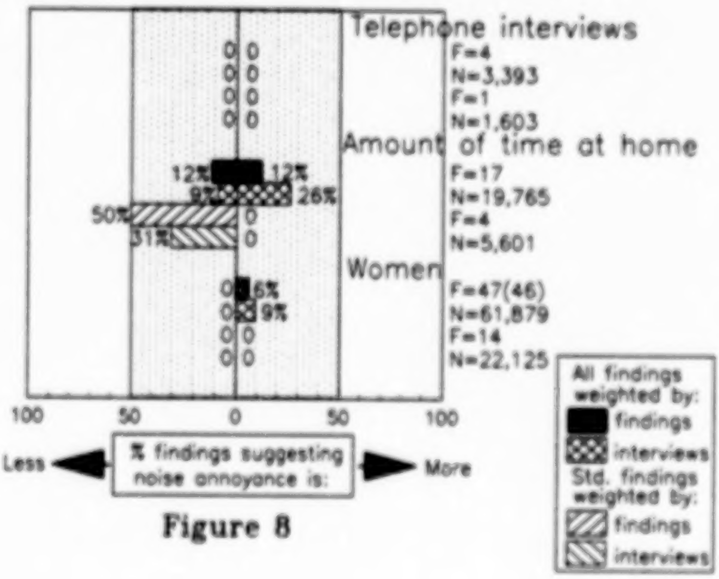


Figure 8

Costs of noise annoyance surveys are affected by the number of interviews and the number of survey locations. A previous analysis of noise surveys' findings reported that there is some homogeneity of reactions within survey areas which cannot be explained by noise level.[22] This homogeneity is commonly expressed as the intraclass correlation coefficient, the average correlation between members within survey areas. In an analysis of 24 annoyance variables from 10 surveys ($N \approx 16,000$ respondents) the median value of the intraclass correlation was found to be rho=0.10. Sampling theory and standard survey sampling practice requires that this clustering of reactions be accounted for in estimating the precision of sample designs.

Table 3 presents estimates of 95% confidence intervals for the proportion annoyed at low noise levels if from 500 to 10,000 interviews were drawn from as few as 10 or as many as 100 areas. The confidence intervals assume that 7% of the population is annoyed and that rho=0.10. These estimated confidence intervals show that a high degree of precision can only be reached with large numbers of survey areas. For example a sample from 10 areas with 10,000 interviews is less accurate than a sample from 20 areas with only 500 interviews. The importance of including a large number of areas is clear, but the confidence intervals which could be expected from different sample designs are only approximate. Quite reasonable alternative assumptions would suggest that a desirable 95% confidence interval of ± 2.5% which is assumed in Table 3 to be achieved with 2,000 interviews in 50 areas might in fact require 2,000 interviews in 75 areas or, on the other hand, only require less than 1000 interviews in 50 areas.

Number of interviews	Number of study areas				
	10	20	30	50	100
500	±5.4	±4.1	±3.6	±3.1	±2.6
1,000	±5.2	±3.8	±3.3	±2.7	±2.2
2,000	±5.1	±3.7	±3.1	±2.5	±1.9
10,000	±5.0	±3.6	±3.0	±2.3	±1.7

Table 3: Estimates of 95% confidence intervals for varying numbers of interviews and study areas (7% annoyed)

Further Research Objectives

What contributions might further secondary analyses or new social surveys make toward estimating en route noise reactions?

Secondary analyses of previously collected, individual-level social survey data could provide more precise estimates of the effects of the variables specified in the hypotheses. The greatest contribution from secondary analyses might be to resolve the conflicting evidence on the changing noise level hypothesis. The surveys with evidence on changing noise levels varied greatly in size and analysis methods. New, parallel secondary analyses could provide standard evidence from the surveys and evaluate the possibility that sampling errors explain some differences.

Secondary analyses could contribute to other issues as well. A rigorous analysis of existing data could estimate the proportion of the population annoyed at low noise levels. To be methodologically sound it is necessary to abandon the previous practice of accepting reviewers' intuitive speculations about the calibration of the various annoyance questions. Combined survey estimates of annoyance levels should only include findings from annoyance scales which have been calibrated against each other within linking surveys.

Secondary analyses could provide a more precise estimate of possible small effects of employment benefits or low ambient noises. Any such effects have been dismissed in this paper because they did not meet the methodology's "importance" criterion. Secondary analyses could more closely specify attitudinal variables and annoyance (fear of crashes, perceived importance) but the analyses could not remove the fundamental doubts about the causal relation between such attitudes and annoyance. Secondary analyses could also serve to summarize the effects of single variables or the combined effects of multiple variables in a form which would be most applicable to noise policy. The effects could be expressed in decibel equivalent penalties or corrections which could be applied to airport/en route comparisons.

New social surveys could also provide useful evidence. A new survey could provide more convincing evidence about reactions at low noise levels if it could overcome doubts about the accuracy of previous surveys' noise measurement techniques which had not been specifically designed for low noise environments. Since there are very few surveys on the direct effect of non-noise nuisances, a new survey might make important contributions on this topic. However, such a survey would need to consider the correlations between noise level and non-noise nuisances and provide strong evidence that errors in long-term noise environment estimation techniques could not bias the estimates of the effects of the non-noise nuisances. New surveys in en route settings would provide the most direct estimates of en route reactions. Such surveys would be most useful for future planning if they were conducted in conjunction with laboratory or other studies which would make it possible to separate the effects of the unique noise source from the effects of the en route setting.

Priorities for Future Research

Measure % annoyed at low noise levels

- Use calibrated questions [Secondary Analysis]
- New survey [NS]

Estimate size of .effect of change (if any) [SA]

Obtain new data on non-noise effects [NS]

Quantify significance and size of effects [SA]

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PREDICTING THE AUDIBILITY AND ANNOYANCE OF UNDUCTED FAN ENGINES

Sanford Fidell, Linda Secrist, and Marie Helweg-Larsen
BBN Systems and Technologies, Inc.
Canoga Park, California

ABSTRACT

Predictions of the prevalence of annoyance associated with aircraft noise exposure are heavily influenced by field studies conducted in urban airport neighborhoods. Flyovers heard in such relatively high ambient noise environments are composed in large part of high absolute level, broadband noise. In contrast, noise exposure created en route by aircraft powered by unducted fan engines is expected to be relatively low in level, but to contain prominent low frequency tonal energy. These tones will be readily audible in rural and other low ambient noise environments.

The annoyance of noise intrusions of low absolute level has been shown to be closely related to their audibility. Thus, one way to predict the annoyance of en route noise generated by unducted fan engines is to estimate its audibility relative to that of conventionally powered aircraft in different ambient noise environments. This may be accomplished by computing the audibility of spectra produced by an aircraft powered by unducted fan engines and comparing predicted probabilities of annoyance for them with those of conventionally powered transport aircraft.

This paper reports on analyses in progress of the annoyance of en route noise produced by aircraft equipped with unducted fan engines. The goal of these analyses is to systematically predict and compare the relative annoyance of the en route noise emissions of such aircraft and of conventionally powered transport aircraft operating under similar conditions. The analyses discussed here focus on predictions of the immediate annoyance of individual noise intrusions as the basis for more elaborate comparisons (such as Fractional Impact Analyses) yet to be completed.

Except for a few unusual cases, residential exposure to en route noise from overflights of conventionally powered transport aircraft has provoked only a fraction of the public reaction created by aircraft noise exposure in immediate airport environs. Differences between the nature of noise emissions of conventional jet engines and those of unducted fan engines (notably, the pronounced low frequency tonality of the latter) raise the possibility that the public may react more vigorously to en route noise exposure produced by aircraft equipped with unducted fan engines than to en route noise produced by conventionally powered aircraft.

If this were so, widespread adoption of unducted fan engines might exacerbate "the aircraft noise problem" in the United States, spreading it from the two million-odd people who reside in the vicinity of large airports to far larger numbers of people who reside in low population density rural areas. There is also reason for heightened concern about reactions to the noise of unducted fan engines in outdoor recreational environments.

The differences in composition of noise emissions of conventional jet engines and unducted fan engines are readily apparent in Figures 1 and 2. Figure 1 is a three dimensional representation of the noise exposure created on the ground beneath a direct overflight of an aircraft equipped with JT8D-15 engines flying at Mach .8 at 35,000 feet. The engine noise heard by an observer on the ground is composed almost exclusively of low frequency, broadband energy.

Figure 2 is a similar representation of the noise exposure produced by a comparable overflight of an aircraft equipped with an experimental unducted fan engine flying at Mach 0.7 at 30,000 feet. The most prominent feature of the noise signature of the unducted fan engine as heard on the ground is the tonal energy emitted at 200 Hz, shown in Figure 2 along with its first harmonic undergoing Doppler shifting during the course of a direct overflight.

The present analyses assess the magnitude of potential reactions to en route exposure produced by unducted fan engines in the United States; more specifically, with noise produced by such engines under cruise conditions (35,000 feet and Mach 0.8). Since unducted fan engines will not be commonplace in commercial aviation in the near future, direct experience cannot as yet provide guidance for these analyses. Instead, as is often the case, the accuracy of such analyses is limited by the large number of order-of-magnitude estimates and assumptions that must be made.

For example, estimates of en route noise exposure require assumptions about the types of aircraft that will be equipped with unducted fan engines, the rate at which such aircraft will be introduced into the fleet, the stage lengths and routes that they will fly, and their daily utilization. Likewise, estimates of community response to en route noise exposure require assumptions about ambient noise conditions and population densities in overflown areas, calculations of the audibility of such exposure, and assumptions about the relationship between the audibility and the annoyance of individual flyovers and cumulative exposure. All of these assumptions entail some amount of uncertainty.

NASA 727 - Event 3

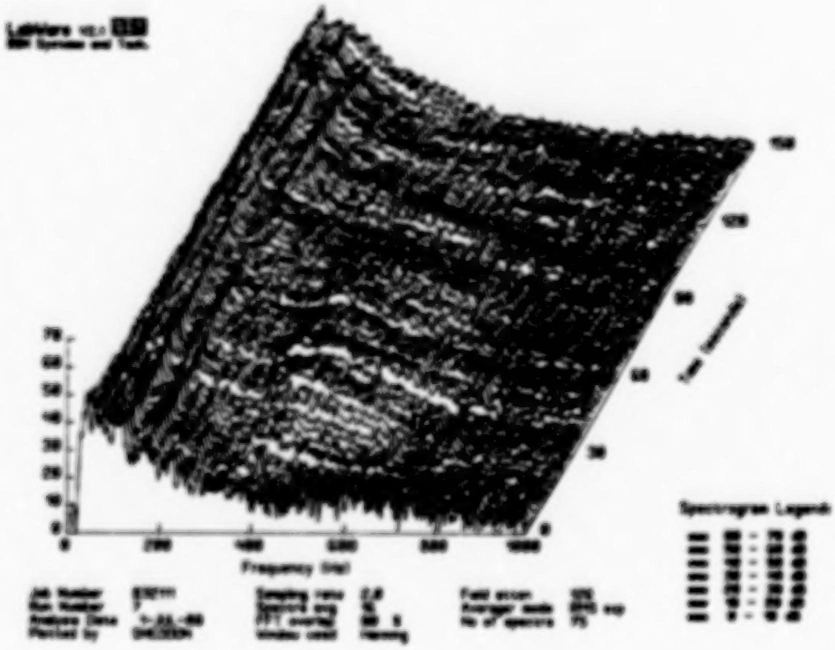


Figure 1*

NASA Propfan - Event 2

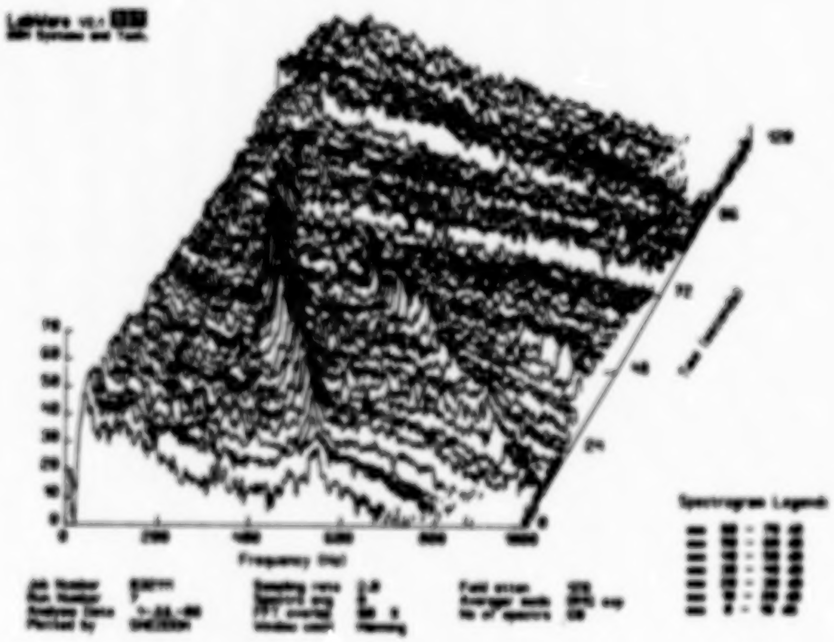


Figure 2*

* Orginial color representation of spectrogram data is shown in black and white. Color figures are available from the authors.

PREDICTION OF NOISE EXPOSURE

Operational information needed for predicting the prevalence of annoyance associated with en route noise exposure can be estimated in a reasonably straightforward manner. It was assumed for present purposes that intermediate range jet transports, such as Boeing 727 and 737 and McDonnell Douglas DC-9 series aircraft, would be those most likely to be replaced by new aircraft equipped with unducted fan engines. Given the backlog of orders that airframe manufacturers currently enjoy, it is unlikely that transport aircraft equipped with unducted fan engines could be built in consequential numbers for several years at a minimum. Furthermore, even if an immediate decision were made to introduce such aircraft into the commercial air transport fleet, the greatest rate at which they could be constructed and put into operation would probably be less than 100 per year.

The domestic commercial air transport fleet currently includes about 2600 B-727s, B-737s and DC-9s. If all of these aircraft are retired within several decades in favor of aircraft equipped with unducted fan engines, and if orders continue to be received during this time for additional intermediate range transports, a rough estimate of the greatest number of commercial transports likely to eventually fly in domestic service with unducted fan engines is 3000. Needless to say, the market for such aircraft could also prove to be far smaller - from nonexistent to perhaps a few hundred aircraft.

A less speculative datum is the total length of high altitude (that is, above 18,000 feet) jet routes in the United States. The sum a few months ago was 171,563 miles. Since new jet routes are generally created when traffic exceeds 100 flights per day per route, it is likely that this figure will climb to something on the order of 200,000 miles by the time that aircraft equipped with unducted fan engines can begin to fly on them in consequential numbers. For purposes of estimating en route noise exposure, however, 20% or so of these route miles in the vicinity of metropolitan areas are of little interest, since aircraft approach and depart cities at relatively low altitudes and speeds.

Before these high altitude route miles can be hypothetically populated with unducted fan aircraft, however, an assumption must be made about their daily utilization. DC-9s, B-737s, and B-727s currently average a bit more than seven hours per day of use in commercial service. There is little reason to believe that utilization of new intermediate range aircraft in a national hub-and-spoke network would deviate appreciably from this figure.

Secondary assumptions are also required about routes that aircraft equipped with unducted fan engines will fly and about the proportion of the time they will spend in cruise conditions. To save time, the net effect of all of these assumptions is summarized in Table 1 without further discussion.

As described later, noise levels produced on the ground during cruise at 35,000 feet are not of sufficiently high absolute level to be readily audible in geographic areas with high ambient noise levels; that is, in high population density (urban) areas. The major interest of the current analyses is therefore in estimating audibility and annoyance outside of metropolitan areas.

The current nonmetropolitan average population density in the contiguous 48 states is about 24 people per square mile, a density that is unlikely to change greatly in the near future. The figure is derived by dividing the number of people living outside the Census Bureau's standard metropolitan statistical areas (SMSAs) by the land area outside of SMSAs, parks, and wilderness areas: roughly 56 million people divided by about 2.3 million square miles. It is necessary to assume for tractable calculations that these people are uniformly distributed throughout the non-

Table 1: Summary of Worst Case Assumptions About Exposure to En Route Noise of Aircraft Equipped with Unducted Fan Engines

Eventual Maximum Number of Aircraft	3,000
Average Hours of Utilization Per Aircraft-Day	7
Total Hours of Daily Fleet Utilization	21,000
Percent of Time in Cruise Conditions	81
Statute Miles Traversed by High Altitude Routes	200,000
High Altitude Statute Route Miles Flown Daily	10,000,000
Daily Overflights of Points throughout Network	50
Maximum Noise Intrusions per hour throughout Network	4

metropolitan land area, even though in reality many of these 56 million people live in small communities.

Assuming further that the 3 dB-down points for audibility of an aircraft flyover at 35,000 feet extend four miles laterally from the flight track, it is possible to estimate an approximate land area of more or less homogeneous noise exposure in the vicinity of high altitude routes. Given a total distance of 200,000 miles for high altitude jet routes, and the assumption that nonmetropolitan areas underlie approximately 80% of distance along these routes, it follows that roughly 30 million people living within an eight mile wide corridor beneath high altitude routes may eventually be exposed to en route noise from unducted fan engines.

The conclusion about noise exposure that all of these assumptions lead to is that if all conventionally powered, intermediate range transport aircraft in the civil fleet are replaced by new aircraft equipped with unducted fan engines, roughly thirty million people residing outside of metropolitan areas of the contiguous 48 states could ultimately be exposed to noise intrusions from at most four overflights per hour throughout the hours of the day during which they are awake.

The number of hourly noise intrusions produced by aircraft equipped with unducted fan engines cannot reasonably be expected to reach this level for many years, however, until virtually all conventionally powered intermediate range transports have been retired from service. A more realistic estimate of the likely number of daily noise intrusions created by aircraft equipped with unducted fan engines within a decade of the start of operations is on the order of one per hour.

The last issue that needs to be addressed before estimates of audibility can be made is the nature of the ambient noise environment in low population density areas throughout the United States. Applying the relationship as described in reference 1 for estimating Day-Night Average Sound Level from population density,

$$L_{dn} = 10 \log (\text{population density}) + 22 \text{ dB}$$

to the present case of 24 people per square mile yields an Ldn of 36 dB. Figure 3 shows the spectral shape for the nighttime ambient noise distribution of a low population density area (5,000 people per square mile) assumed for the analyses conducted to date. Also plotted on the figure are similar spectra of assumed ambient noise distributions for inhabited areas of higher population density, and for an uninhabited area.

All of the working assumptions necessary to calculate the audibility of unducted fan engines are now in place. It should be stressed that these are in fact nothing more than working assumptions: because conclusions may be quite sensitive to these working assumptions, inferences eventually drawn from the present analyses will differ as alternative assumptions are considered. Sidestepping further discussion about the details of assumptions, however, the next step is to estimate audibility.

Audibility is defined for present purposes as bandwidth and duration adjusted signal to noise ratio, expressed in the scalar quantity d'-seconds. Following the conventions for conducting these calculations in one-third octave bands adopted in software packages such as the U.S. Army Acoustic Detection Range Prediction Model, values of d' can be calculated as

$$d' = \sqrt{\eta \quad BW} \; S/N$$

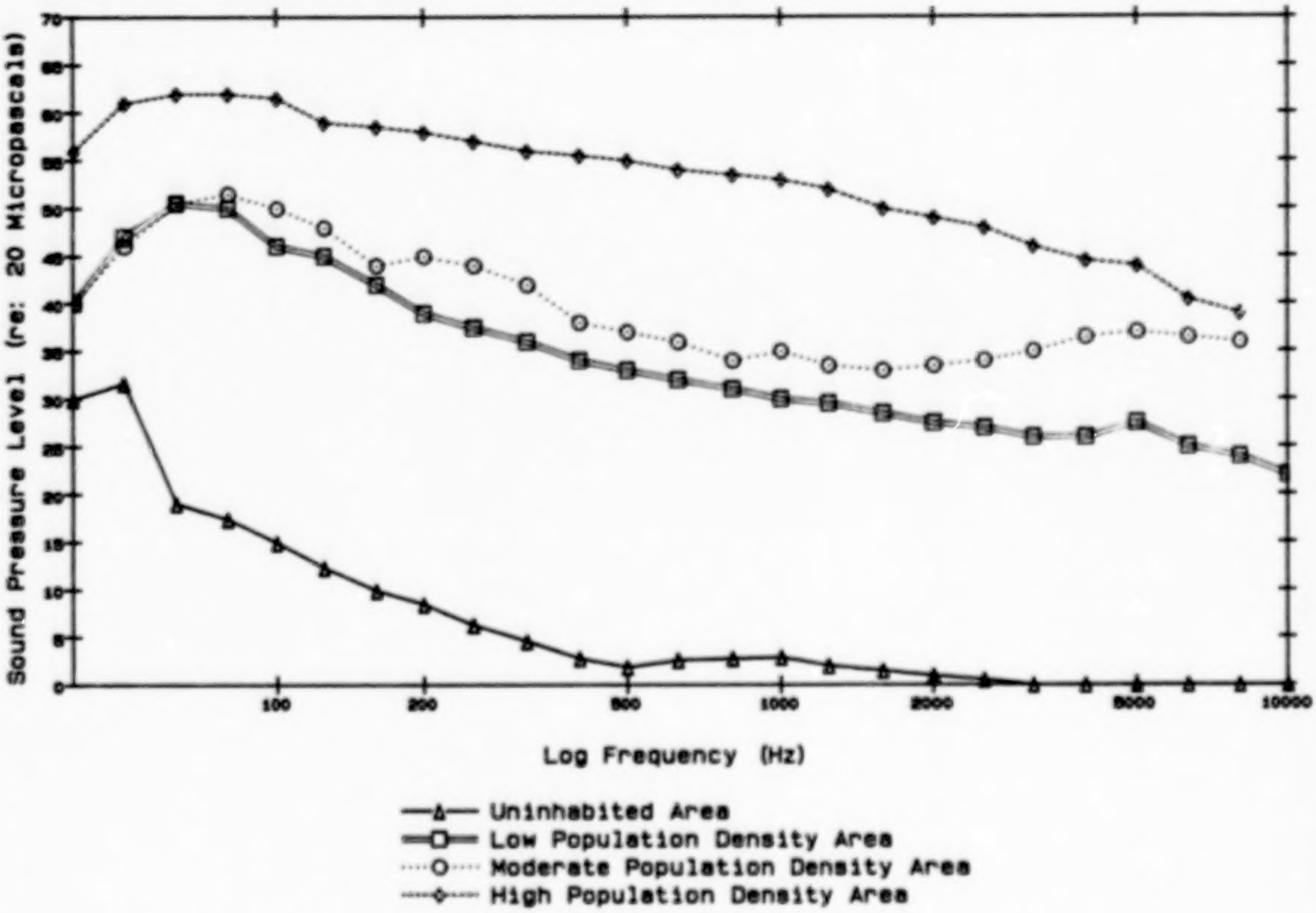


Figure 3: Assumed One-Third Octave Band Ambient Noise Spectra for Low, Moderate and High Population Density and Uninhabited Areas

where eta represents the efficiency of the observer relative to an ideal energy detector, BW is the bandwidth of the detector's passband, and S/N is the signal to noise ratio.

ASSUMPTIONS ABOUT REACTIONS TO NOISE EXPOSURE

Just as estimating en route noise exposure requires a rationale and supporting assumptions, so does the process of estimating individual and community response to the exposure. The most straightforward way to compare the annoyance of noise signatures of hypothetical aircraft powered by unducted fan engines with the annoyance of existing aircraft is to establish an equivalence in terms of the probability of immediate, short term annoyance associated with individual overflights. The equivalence in annoyance can then be manipulated to develop predictions of equivalent numbers of operations of different aircraft types, equivalent prevalence of annoyance, and other derivative measures.

The first requirement is a transfer function relating audibility to the immediate annoyance of individual overflights. Such a function can be derived from laboratory findings on the relationship between audibility and annoyance of individual noise intrusions. Two such data sets (references 2 and 3) have been analyzed to produce the averaged cumulative relationships seen in Figure 4.

These transfer functions can yield predictions of the audibility and annoyance of flyovers of any sort. Only certain flight conditions are of interest for purposes of estimating the annoyance associated with en route noise exposure, however; that is, a speed of Mach 0.8 at an altitude of 35,000 feet. Thus, aircraft recordings made under other conditions require adjustment to these conditions. The recording of an aircraft equipped with an unducted fan engine available for the present analyses produced by an aircraft at an altitude of 30,000 feet and a speed of Mach 0.7. Inverse square and atmospheric absorption adjustments were therefore made to the recorded spectrum to convert it to standard cruise conditions.

Perhaps the most obvious case for which an annoyance prediction is of interest is that of the actual noise signature of a direct overflight of an aircraft equipped with a prototype version of an unducted fan engine. The most useful interpretations of the predicted audibility and annoyance of such a flyover are in terms of the predicted audibility and annoyance of comparable flyovers of Stage II and Stage III aircraft. Accordingly, similar calculations were made for a B-727 equipped with JT8D-15 engines and for a DC-10 with its high bypass ratio engines. Inverse square and atmospheric absorption corrections were also made to recorded spectra of these Stage II and Stage III aircraft to adjust them to standard cruise conditions. The resulting flyover spectra are seen in Figure 5.

As may be seen in Figure 6, the audibility of the aircraft powered by an unducted fan engine in the very low ambient noise environment assumed to be characteristic of uninhabited areas is so great that it is a certainty that the noise intrusion would be judged highly annoying. The odds are about even that the overflight would be judged highly annoying in the ambient noise environment assumed for low population density area, roughly two to one against a highly annoying judgment in an area of moderate population density, and about ten to one against a highly annoying judgment in a densely populated metropolitan area. Figures 7 and 8 display comparable information for Stage II and Stage III aircraft.

Generalizations about the annoyance of en route noise produced by aircraft equipped with unducted fan engines should not be based solely upon an analysis of a single flyover. In particular, it is unclear whether production engines would be as noisy as the prototype engine. Furthermore,

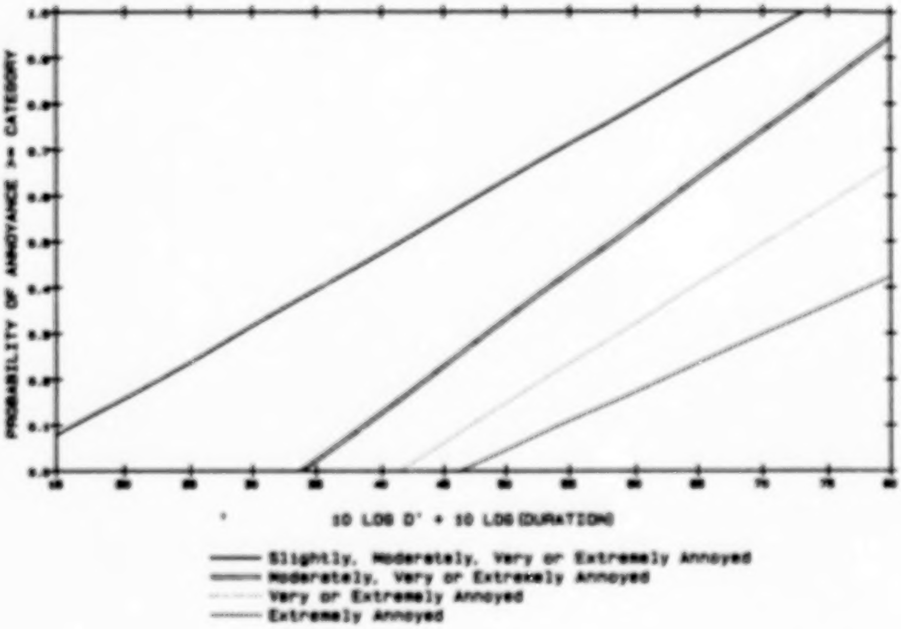


Figure 4: Average Least-Squares Fits to Cumulative Distribution of Annoyance Ratings (From Fidell and Teffeteller (1981) and Fidell, Silvati and Secrist (1989))

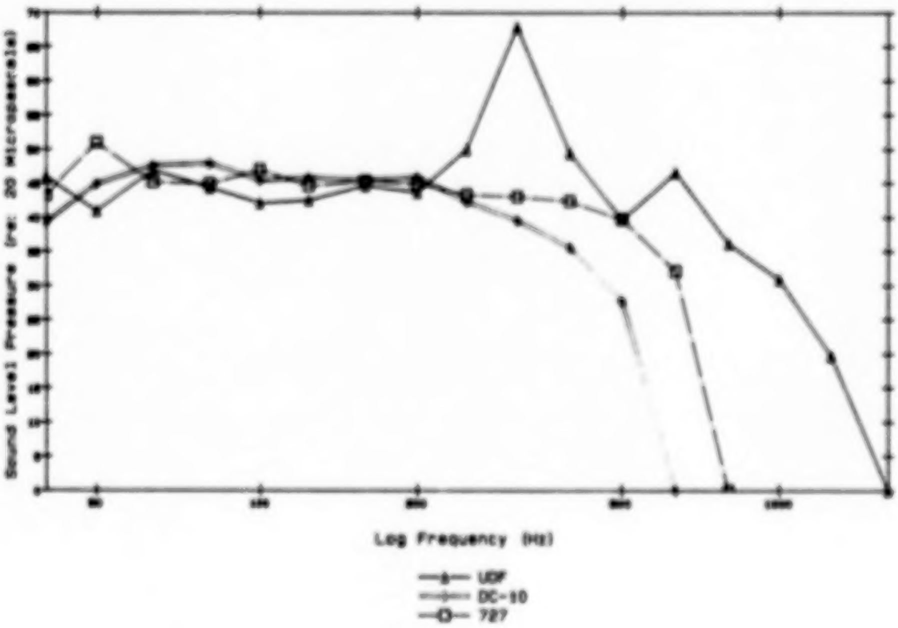
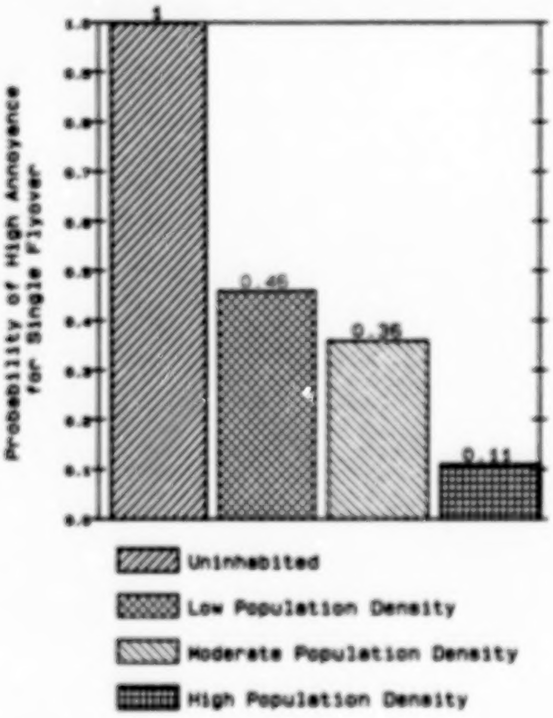


Figure 5: One-Third Octave Band Spectra of En Route Noise Emissions of B-727, DC-10 and UDF-Powered Aircraft at CPA (Adjusted to 35,000')



*Adjusted to 35,000'

Figure 6: Predicted Probability of High Annoyance Associated with an Actual Overflight* of UDF-Powered Aircraft (A-Level = 64.9 dB)

*Adjusted to 35,000'

Figure 7: Predicted Probability of High Annoyance Associated with an Actual Overflight* of JT8D-15 Powered (B-727) Aircraft (A-Level = 43.6)

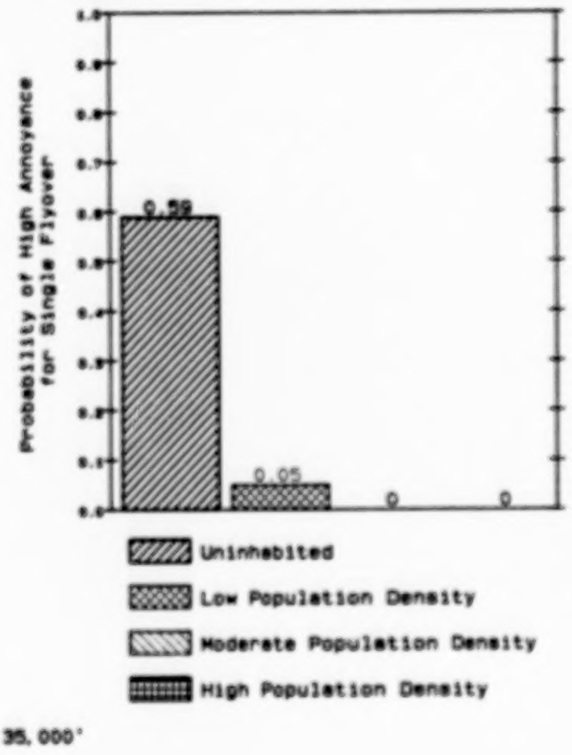


Figure 8: Probability of High Annoyance Associated with an Actual Overflight* of Stage 3 (DC-10) Aircraft (A-Level = 44.7 dB)

details of assumptions and calculation procedures matter. Factors such as the criterion of audibility, the points in time during the flyover which contribute to the definition of A-weighted Sound Exposure Level, the total duration of the flyover, and corrections for Doppler shifts can all influence conclusions drawn from these analyses.

Nonetheless, it is interesting to speculate on the relative annoyance of unducted fan and conventional engines at levels other than those for which recordings are available. For example, would aircraft equipped with unducted fan engines be more or less annoying than Stage II and Stage III aircraft to an observer outdoors if they produced the same A-weighted noise signatures?

The next three figures address this issue. Figures 9, 10, and 11 show the predicted probability of annoyance associated with single overflights of the three aircraft types at different A-weighted sound pressure levels in different ambient noise environments. The trends shown in the figures are not surprising: the probability of annoyance is greatest in the lowest population density ambient noise environment and rises with A-weighted sound pressure level in all ambient noise environments. It is interesting to note, however, that although the predicted probability of annoyance of an overflight of an aircraft powered by an unducted fan engine is greater than that of a Stage III aircraft such as a DC-10, it does not differ substantially from that of a Stage II aircraft such a B-727.

The next step in the analyses now in progress is to apply the equivalences established between the short term annoyance of flyovers of aircraft equipped with unducted fan and other engines to predictions of long term annoyance made with reference to a dosage-effect relationship such as that described in reference 4. Among the additional factors to be considered in the coming months are the effects of numbers of occurrences of flights (as discussed, for example, by in references 5 and 6), the sensitivity of conclusions to minor changes in assumptions, and the definition of exposure zones for Fractional Impact Analyses.

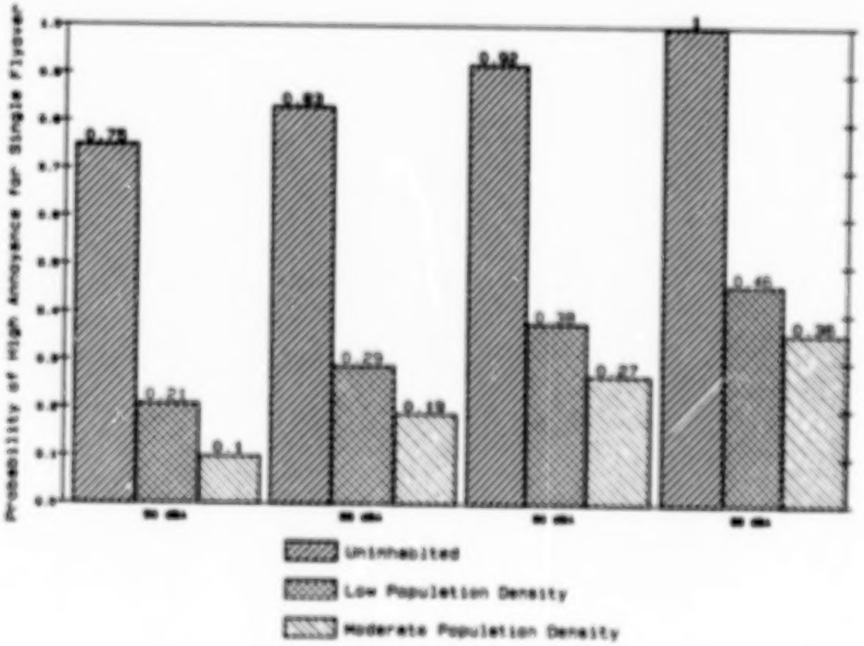


Figure 9: Predicted Probability of High Annoyance Associated with an Individual Overflight of UDF-Powered Aircraft

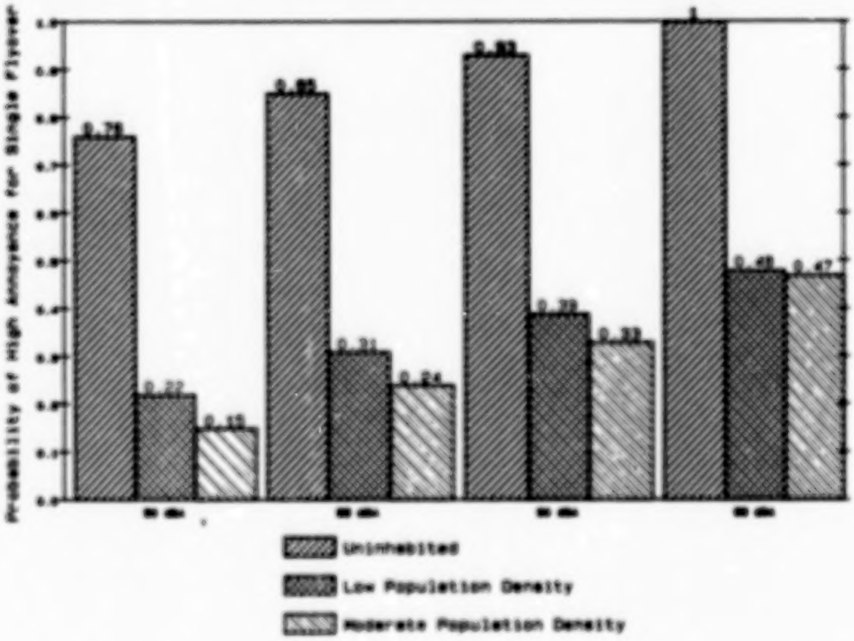


Figure 10: Predicted Probability of High Annoyance Associated with an Individual Overflight of JT8D-15 Powered (B-727) Aircraft

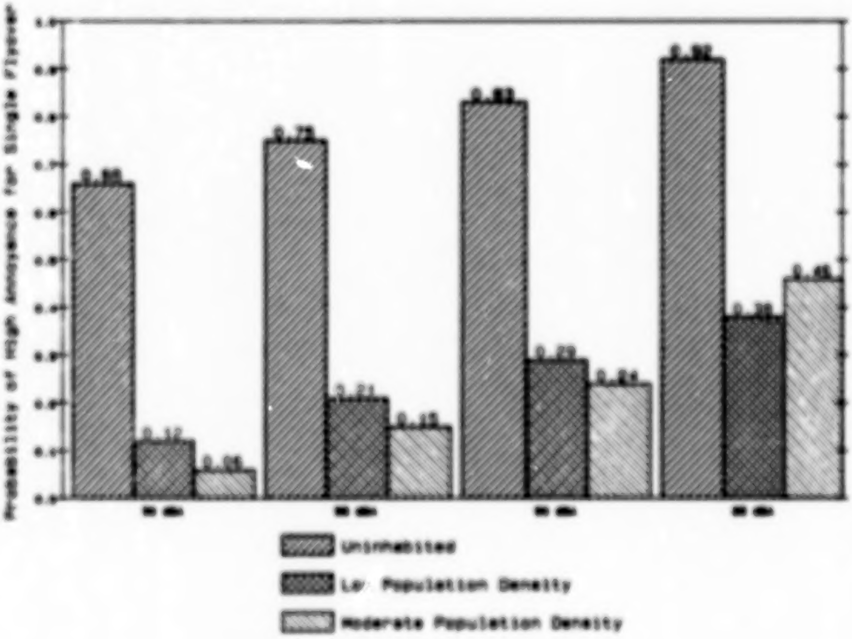


Figure 11: Predicted Probability of High Annoyance Associated with an Individual Overflight of Stage 3 (DC-10) Aircraft

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Acknowledgments

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EN ROUTE NOISE ANNOYANCE LABORATORY TEST - PRELIMINARY RESULTS

David A. McCurdy

NASA Langley Research Center
Hampton, Virginia

A symbols and abbreviations list appears at the end of this paper.

INTRODUCTION

Until recently concerns about the impact of aircraft noise on people have centered around the takeoff and landing operations of aircraft in the vicinity of airport terminals. The development of the advanced turboprop (propfan) engine, modifications to air corridors, and the desire to maintain a natural environment in national parks and recreation areas have now focused attention on the impact at ground level of the en route noise produced by aircraft at cruise conditions and altitudes. Compared to terminal area noise, en route noise is characterized by relatively low noise levels, lack of high frequency spectral content, and long durations. Much research has been directed towards understanding and quantifying the annoyance caused by terminal area aircraft noise, but relatively little research has been conducted for en route noise. To address this need, a laboratory experiment was conducted to quantify the annoyance of people on the ground to en route noise generated by aircraft at cruise conditions. The objectives of the experiment are given in figure 1.

OBJECTIVES

- Determine the annoyance prediction ability of noise measurement procedures and corrections when applied to en route noise.

- Determine differences in annoyance response to en route noise and takeoff/landing noise.

- Determine differences in annoyance response to advanced turboprop en route noise and conventional jet en route noise.

Figure 1

EXPERIMENT DESIGN

Figure 2 describes the noise stimuli used in the experiment. Thirty-four noises were presented to test subjects at three nominal L_D levels of 60, 70, and 80 dB. Six additional presentations of the B-727 takeoff noise were made at L_D levels of 50, 55, 65, 75, 85, and 90 dB for a total of 108 noise stimuli. The advanced turboprop en route noises were recordings of the NASA Propfan Test Assessment aircraft made during tests at the White Sands Missile Range in New Mexico. The conventional jet en route noises were recorded near Gordonsville, Virginia, by the DOT Transportation Systems Center.

- **8 PTA ADVANCED TURBOPROP EN ROUTE NOISES**
  - **ALTITUDES: 30k, 15k, 9k, 2k ft.**
  - **MACH NUMBERS: .5, .7, .77**
  - **DURATIONS: ~ 40 to 160 sec.**
- **6 CONVENTIONAL JET EN ROUTE NOISES**
  - **B-727, B-737, B-757, B-767, DC-9, DC-10**
  - **ALTITUDES: 28k to 37k ft.**
  - **DURATIONS: ~ 40 to 160 sec.**
- **10 CONVENTIONAL TURBOPROP TAKEOFF AND LANDING NOISES**
  - **DASH-7, P-3, YS-11, NORD 262, SHORTS 330**
  - **DURATIONS: ~ 30 to 60 sec.**
- **10 CONVENTIONAL JET TAKEOFF AND LANDING NOISES**
  - **A-300, B-707, B-727, DC-9, DC-10**
  - **DURATIONS: ~ 30 to 60 sec.**
- **EACH NOISE PRESENTED AT 3 LEVELS**
  - **NOMINAL L_D = 60, 70, 80 dB**
- **32 TEST SUBJECTS**

Figure 2

EN ROUTE NOISE L_A TIME HISTORIES

L_A time histories of two of the en route noises are shown in figure 3. The time histories illustrate three features of special interest: (1) the different time history shapes caused by the presence of low frequency pure tones in the PTA noise (see figure 4); (2) the large fluctuations in level with time; and (3) the long duration of the noises.

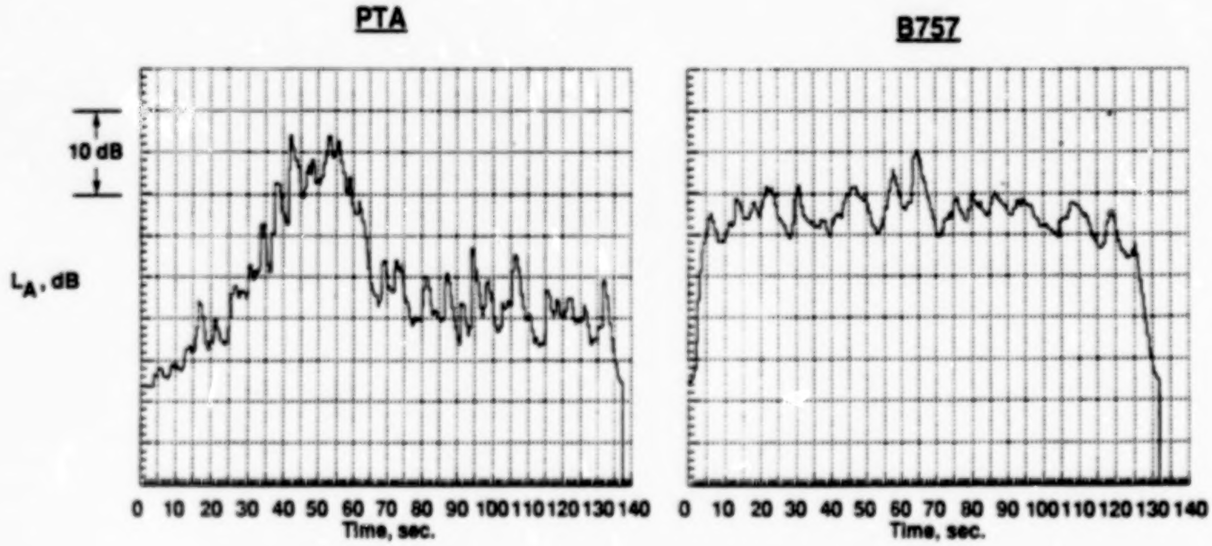

Figure 3

EN ROUTE NOISE SPECTRA AT PEAK L_A

One-third-octave-band spectra at peak L_A of two of the en route noises are shown in figure 4. The two spectra illustrate the main spectral difference between advanced turboprop and conventional jet en route noise. The advanced turboprop spectrum is dominated by a low frequency pure tone at the blade passage frequency; whereas, the conventional jet spectrum is predominantly low frequency broadband noise.

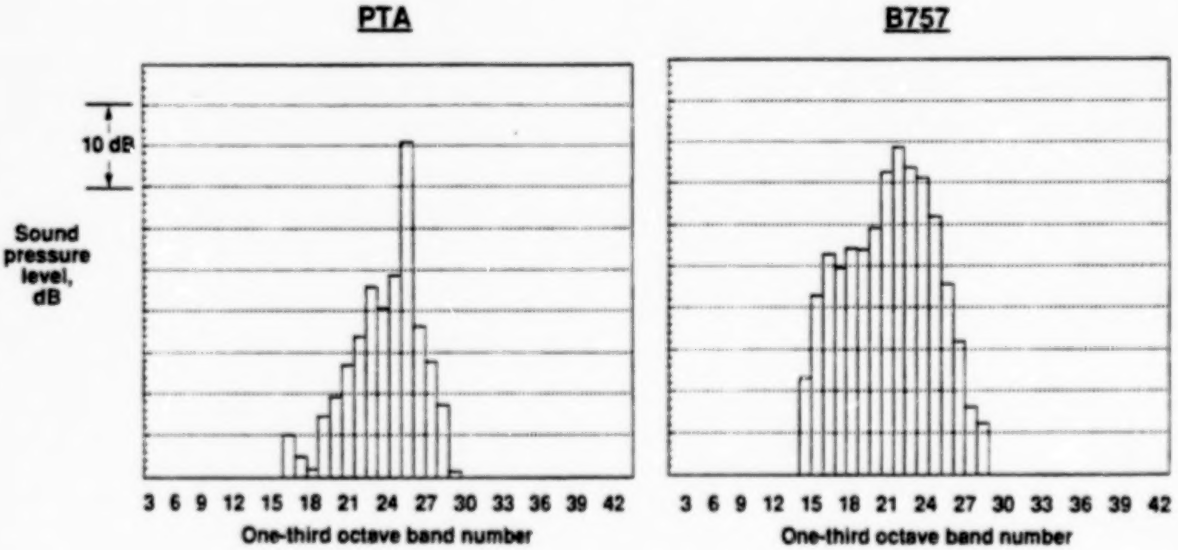

Figure 4

TEST FACILITY

A small anechoic room in the Langley Acoustics Research Laboratory was used as the test facility in the experiment (figure 5). Thirty-two test subjects judged the annoyance of each noise stimulus using a numerical category scale. The scale was a unipolar, 11 point scale from 0 to 10. The end points of the scale were labeled "EXTREMELY ANNOYING" and "NOT ANNOYING AT ALL." The term "ANNOYING" was defined in the subject instructions as "UNWANTED, OBJECTIONABLE, DISTURBING, OR UNPLEASANT."

Figure 5

CONVERSION OF ANNOYANCE JUDGMENTS TO SUBJECTIVE NOISE LEVELS

The means (across subjects) of the annoyance judgments were calculated for each stimulus. In order to obtain a subjective scale with meaningful units of measure, these mean annoyance scores were converted to "subjective noise levels," L_S, having decibel-like properties through the following process. Included in the experiment for the purpose of converting the mean annoyance scores to L_S values were six additional presentations of the B-727 takeoff recording having L_D values of 50, 55, 65, 75, 85, and 90 dB. A third order polynomial regression analysis was performed using data obtained for the nine B-727 stimuli. The dependent variable was the calculated PNL and the independent variable was the mean annoyance score for each of the nine stimuli. The regression equation thusly determined was subsequently used to predict the level of the B-727 takeoff noise which would produce the same mean annoyance score as each of the other noise stimuli in the experiment. These levels were then considered as the "subjective noise level" for each stimulus.

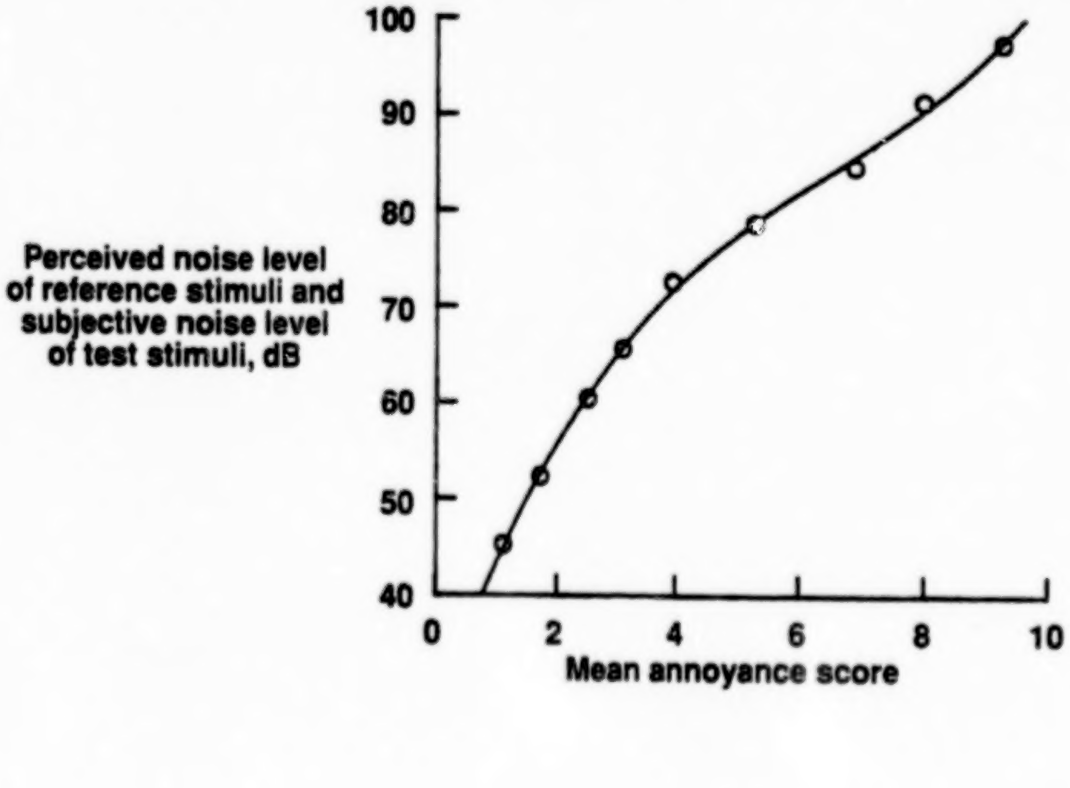

Figure 6

NOISE MEASUREMENT PROCEDURES AND CORRECTIONS

Each noise stimulus was analyzed to provide one-third-octave band sound pressure levels from 20 Hz to 20 kHz for use in computing a selected group of noise metrics. In addition to OASPL, the group included the simple weighting procedures L_A and L_D and the more complex calculation procedures LL_Z, PL, and PNL. Twelve different variations of each of the noise procedures were calculated. The first was the peak or maximum level occurring during the noise. Two other variations were calculated by applying two different tone corrections. Nine more variations were attained by applying three different duration corrections to the non-tone corrected level and the two tone corrected levels. The first duration correction and the first tone correction are identical to those used in the EPNL procedure defined in the Federal Aviation Administration FAR 36 regulation (ref. 1). The second tone correction is identical to the first except that no corrections are applied for tones identified in bands with center frequencies less than 500 Hz. The second and third duration corrections were identical to the first except that the corrections were based on the 15 and 20 dB down points instead of the 10 dB down points.

Comparisons of the different noise metrics and the subjective noise level were made to determine the annoyance prediction ability of each noise metric when applied to the en route noise stimuli. Basing the duration correction on the 15 and 20 dB down points instead of the 10 dB down points did not improve annoyance prediction. The effects of duration and tone corrections on annoyance prediction were inconsistent across noise procedures. Based on preliminary analyses, L_A with duration and tone corrections was the best predictor of annoyance to en route noise.

MEASUREMENT PROCEDURES	TONE CORRECTIONS	DURATION CORRECTIONS
OASPL	NONE	NONE
L_A	FAR 36	D_{10}
L_D	FAR 36 ≥500Hz	D_{15}
PNL		D_{20}
PL		
LL_Z		

Figure 7

COMPARISON OF ANNOYANCE RESPONSES USING L_A

Figure 8 compares the annoyance responses to PTA aircraft at cruise, conventional jet aircraft at cruise, and conventional turboprop and jet aircraft takeoffs and landings. The figure plots subjective noise level versus L_A for each of the three combinations of aircraft type and operation. Simple linear regression lines for each of the three combinations are also shown. For L_A, the conventional jet cruise noises were slightly more annoying than the PTA cruise noises. Although the differences in annoyance are small, indicator (dummy) variable analyses for L_A show significant differences in slope and intercept between the appropriate regressions for the three sets of noises.

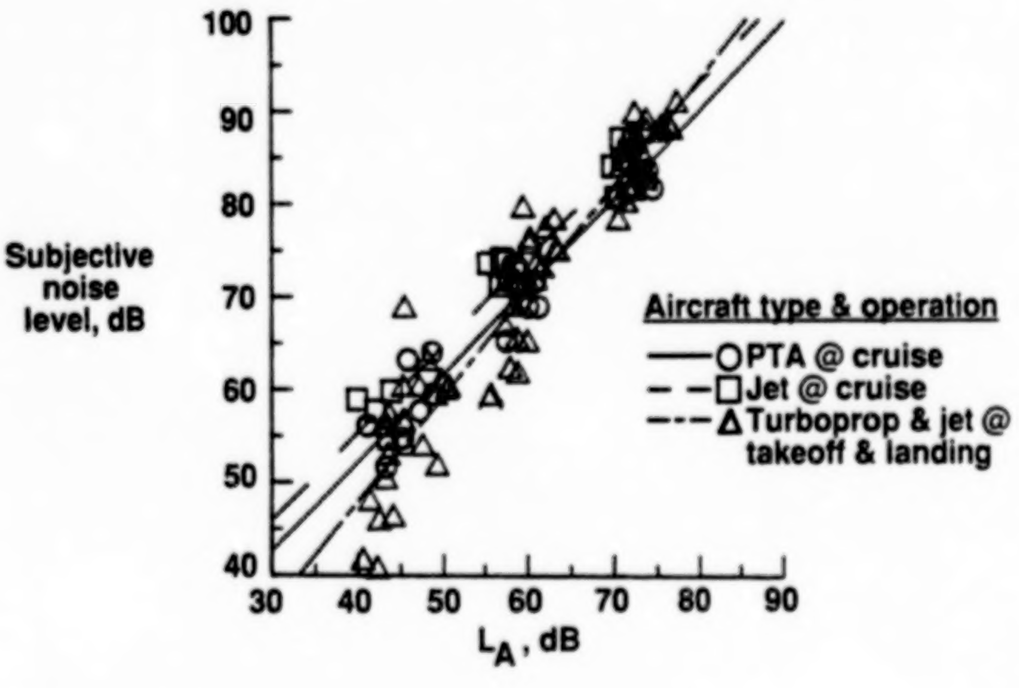

Figure 8

COMPARISON OF ANNOYANCE RESPONSES USING DURATION CORRECTED L_A

Figure 9 compares the annoyance responses to PTA aircraft at cruise, conventional jet aircraft at cruise, and conventional turboprop and jet aircraft takeoffs and landings using duration corrected L_A. Adding duration corrections to L_A results in the conventional jet cruise noises being slightly less annoying than the PTA cruise noises. This is the reverse of the results in figure 8 for L_A. As in the previous figure, indicator variable analyses indicate significant differences in slope and intercept between the appropriate regressions for the three types of noises.

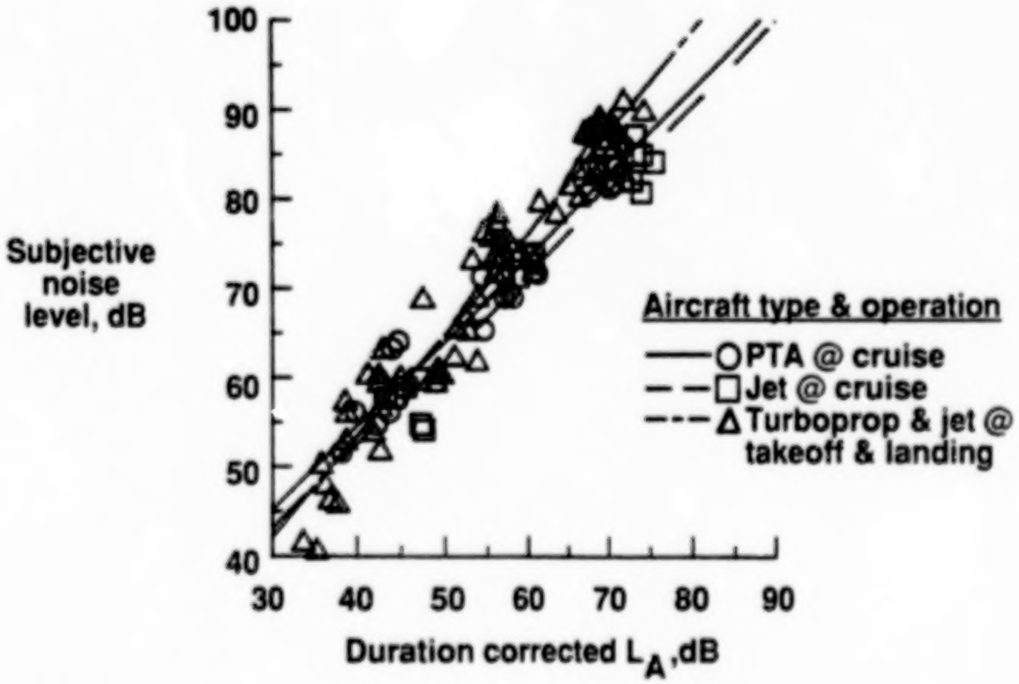

Figure 9

COMPARISON OF ANNOYANCE RESPONSES USING EPNL

Figure 10 compares the annoyance responses to PTA aircraft at cruise, conventional jet aircraft at cruise, and conventional turboprop and jet aircraft takeoffs and landings using EPNL. Results are similar to those for duration corrected L_A in figure 9.

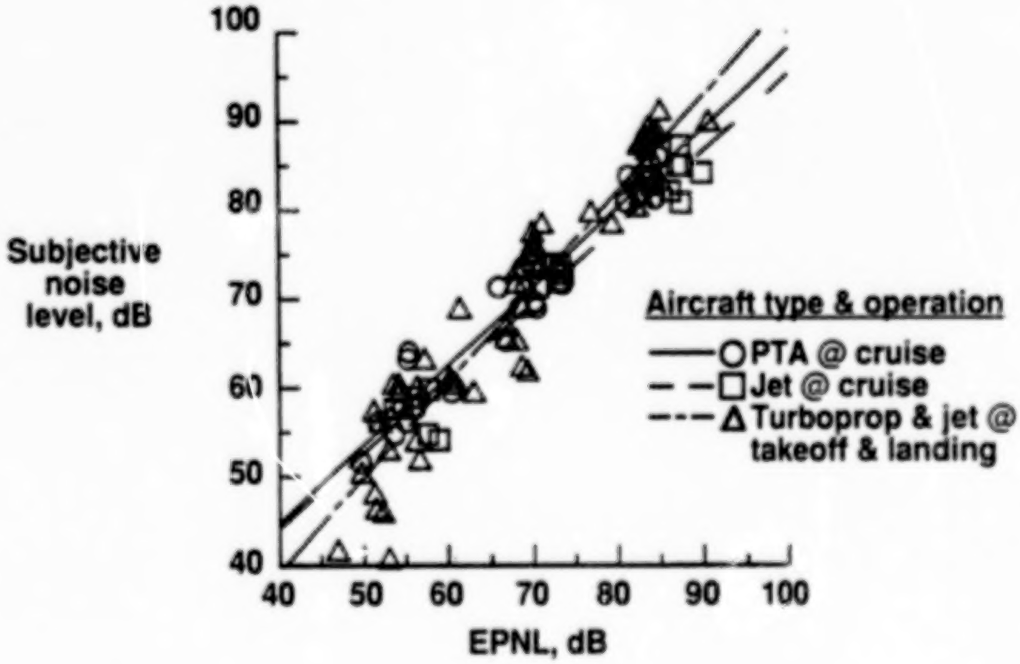

Figure 10

SUMMARY

A laboratory experiment was conducted to quantify the annoyance of people on the ground to en route noise generated by aircraft at cruise conditions and altitudes. Thirty-two test subjects judged the annoyance of 24 PTA advanced turboprop en route noise stimuli; 18 conventional jet en route noise stimuli; and 60 conventional turboprop and jet takeoff and landing noise stimuli in an anechoic listening facility. Figure 11 lists the preliminary results.

- **Based on preliminary analyses and results**
  - **Significant differences in annoyance response between en route noise and takeoff/landing noise**
  - **Significant differences in annoyance response between advanced turboprop and conventional jet en route noise**
  - **Effects of duration and tone corrections are inconsistent**
  - **L_A with duration and tone corrections is best predictor of annoyance to en route noise**

Figure 11

SYMBOLS AND ABBREVIATIONS

ATP	advanced turboprop
EPNL	effective perceived noise level, dB (ref. 1, 2)
FAR	Federal Aviation Regulation
L_A	A-weighted sound pressure level, dB (ref. 2)
L_D	D-weighted sound pressure level, dB (ref. 2)
L_S	subjective noise level, dB
LL_Z	Zwicker's loudness level, dB (ref. 2)
OASPL	overall sound pressure level, dB (ref. 2)
PL	perceived level (Stevens Mark VII procedure), dB (ref. 2)
PNL	perceived noise level, dB (ref. 1, 2)
PTA	Propfan Test Assessment

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PROBLEMS RELATED TO AIRCRAFT NOISE IN SWITZERLAND

J. Rabinowitz
Centre Universitaire d'écologie humaine et
des sciences de l'environnement de l'Université de Genève
Carouge, Switzerland

SUMMARY

Some of the problems related to aircraft noise such as aircraft noise indices, immission standards, land use planning, en route noise and general sensitivity to noise are briefly discussed.

PROBLEMS RELATED TO AIRCRAFT NOISE IN SWITZERLAND

In Switzerland the Noise and Number Index (NNI) has been chosen to quantify the exposure to aircraft noise in the communities surrounding the three national airports (Geneva-Cointrin, Basle-Mulhouse and Zürich-Kloten):

$$NNI = \overline{PNL} - 80 + 15 \log N$$

$\overline{PNL}$ is the mean value of the peak perceived noise levels exceeding 80 PNdB, and N is the daily number of aircraft movements (exceeding that level) from 06 to 22 hours averaged over a year.

The regulations concerning land use restrictions around these airports are based on the NNI index and apply to three noise zones. Zone A is the noisiest with NNI values of above 65, zone B is located between 55 and 65 NNI contours, and zone C between 45 and 55 contours. Construction of new dwellings, with proper sound insulation, are allowed only in zone C.

Surveys around the three national airports were conducted in the early seventies' (ref. 1) and the authors at that time found a good correlation between community annoyance and the Noise and Number Index (the correlation was even higher when a slightly modified NNI formula was used). However, over the last years, this index has come under criticism, especially in the United Kingdom where it was first introduced (ref. 2). The Swiss federal commission of experts for the evaluation of maximal noise immission values (immission standards) is also considering the possibility of switching from the NNI index to a sound equivalent level (Leq) based index, as is already the case in Switzerland for exposure to other types of noises, according to the general formula: Lr = Leq + K. The commission has still to determine these immission values with regard to exposure to aircraft noise around the national airports. This has already been done for other types of noises (road traffic noise, regional airports and helistations, train noise, etc.) and the corresponding Lr values are published in the Ordinance on protection against noise "OPB" (ref. 3) as required by the Federal law of environmental protection "LPE" (ref. 4).

Three sets of standards are generally given for noise immission values: a) planning values (the lowest, are concerned for example with dwellings in new building zones); b) maximal immission values (concern existing building zones); and c)

"alarm" values (are the highest, and when exceeded, some action like the sound insulation of dwellings must be undertaken).

Another problem that has arisen, as in other countries, is that of annoyance caused by military aircraft noise. As a result, tentative regulations have been submitted for consultation to all the interested parties (state, political and other interested organizations) which is the usual procedure before the final regulations are issued and enforced.

Helicopter noise has also become a source of annoyance, especially in mountain areas. The noise of helicopters is generally well accepted by the local communities when they are on a life saving mission, but not when they are used for heliskiing; consequently, the number of sites where heliskiing is permitted has had to be limited to a maximum of 48.

People are now well aware and sensitive to environmental problems; not wanting to be exposed to aircraft noise, they often solicit the airport noise authorities for advice concerning the location of the property they intend buying.

Two other major problems of concern are how to reconcile the continuous growth of airports and the land use restrictions in the surrounding communities; secondly, how to maintain the night curfew presently in force in the mentioned airports.

It is worthwile to notice that complaints regarding aircraft noise arise now from areas more distant from airports than they used to be ten years ago. En route noise itself is still a minor problem. Most of the complaints come from the Swiss Plateau (close to the German border) and concern mostly propeller airplanes, although some complaints about jet aircraft have been reported in very quiet touristic regions. The major reason for complaints is sleep disturbance, and en route noise might become a problem if the frequency of night overflights increases sharply.

Some concern also arises from the possible future introduction of aircraft powered by new technology engines (ie. propfans) and which may have significant different noise characteristics compared to jet airplanes of today. One of the subjects discussed in this context is the introduction of en route noise certification. If such a procedure should be adopted, despite costs and inherent difficulties of reliable measurements, one of the criteria to be taken into account should be that en route aircraft do not wake up people in bedrooms with open windows in otherwise quiet areas. Generally recommended levels to avoid sleep disturbance is that in bedrooms Leq (night) should not exceed 35-40 dB(A) and that individual peak levels should remain under 50-55 dB(A), depending on the type of noise (continuous or intermittent), the number of peaks and the difference between peak level and background level (refs. 5, 6 and *).

Since the surveys concerning the three national airports were done some 17-18 years ago, check studies could be necessary to ascertain that those results are still valid. Such check studies have been conducted in France (ref. 7), the Netherlands (ref. 8) and the United Kingdom (refs. 9 and 10), and suggest that

* Griefahn, B.: Sleep in noisy environments. Review and further research. To be published in Environment International.

community annoyance (or sleep disturbance) related to aircraft noise exposure indices used in those countries (dose-response relationship) has not changed significantly over the years.

General sensitivity to noise is one of the important emotional variables affecting individual response to noise. People are generally divided into three noise sensitivity categories: high, moderate (or normal) and low. In a recent survey in Geneva (ref. 11), we found that around 25 per cent of the population in noisy (exposed to road traffic noise) and quiet neighborhoods considered themselves as being very sensitive to noise and that this percentage was not significantly age dependent (except for adolescents aged 13 to 15 years). But low sensitivity to noise decreased with age up to 65 years and then increased sharply. It would be interesting to verify if comparable results are obtained from the population exposed to aircraft noise. A better apprehension of the effects of aircraft noise in the presence of other noise sources is also desirable.

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AN AIRCRAFT NOISE STUDY IN NORWAY

Truls T Gjestland
and
Kåre H Liasjø
ELAB-RUNIT The Norwegian Institute of Technology

N-7034 Trondheim, Norway

Hans Einar Bøhn
Civil Aviation Administration
Oslo, Norway

Introduction

An extensive study of aircraft noise is currently being conducted in Oslo, Norway. The traffic at Oslo Airport Fornebu that includes both national and international flights, totals approximately 350 movements per day: 250 of these are regular scheduled flights with intermediate and large size aircraft, the bulk being DC9 and Boeing 737.

The political decision to build a new airport to replace Fornebu has already been made, but until the late nineties the problems with aircraft noise in Oslo will continue, and to some degree they are also expected to increase.

During the summer months of 1989, Oslo Airport Gardemoen, which serves most of the charter traffic and intercontinental traffic, was being refurbished. From May till September the major part of the traffic was therefore transferred to Fornebu.

The total traffic during the summer of 1989 was expected to resemble the maximum level to which the regular traffic will increase before the new airport can be put into operation. The situation therefore represented a unique possibility to study the noise impact on the communities around Fornebu.

Outline of noise study

A comprehensive social survey was designed, including questions on both aircraft and road traffic noise. A random sample of 1650 respondents in 15 study areas were contacted for an interview. These areas represent different noise levels and different locations relative to the flight paths.

The interviews were conducted in a 2 week period just prior to the transfer of charter traffic from Gardemoen to Fornebu.

In the same period the aircraft noise was monitored in all 15 areas. In addition the airport is equipped with a permanent flight track and noise monitoring system. The noise situation both in the study period and on an average basis can therefore be accurately described.

In Norway the official aircraft noise exposure index is called EFN. This index is quite similar to CNEL. However, we have also calculated LDN at Fornebu. For this particular aircraft mix and traffic pattern the difference between EFN and LDN was slightly less than 1 dBA, with EFN being the larger quantity. There is a partly effective night curfew at Fornebu with no scheduled operations between 11 pm and 7 am.

In August a group of 1800 new respondents were subjected to identical interviews in the same 15 areas, and the noise measurement program was repeated.

Results

Only the results from the spring survey have been analyzed so far. In this report we will present the responses to a direct question on reaction to aircraft noise.

The respondent was asked: "Can you hear aircraft noise when being outside your home ?", and if the answer was YES, we presented a follow-up question: "Would you consider this noise very annoying, moderately annoying, a little annoying or not annoying ?" (The original questionnaire was naturally written in Norwegian, and these examples have been translated).

The results are given in Figure 1. The diagram shows the percentage (of the total number of people asked: Can you hear aircraft noise....) considering the noise very annoying as a function of the outdoor aircraft noise level in each location.

Models for noise annoyance

A number of attempts have been made to give a mathematical description of the relationship between degree of annoyance and noise exposure. In 1978 Schultz (1) presented his well known synthesis, describing the percentage "highly annoyed" by a third order polynominal, see Figure 2.

Schultz's relationship was purely empirical, and as it is pointed out in a later publication (2), it was lacking a theoretical foundation.

We have previously presented a model based on the introduction of a threshold (3), assuming that only noise above a certain level could contribute to the annoyance. This concept has been validated by laboratory experiments (4), and we concluded that the energy-equivalent noise level calculated for noise above a given threshold is a good descriptor for noise annoyance.

Fidell et al. (2) have shown that differences between dose-response relationships that have appeared in different noise surveys can be accounted for by using a very simple model based on a fixed threshold and varying criterion value associated with different communities, see Figure 3.

A further elaboration on the threshold concept has led us to suggest the following hypothesis:

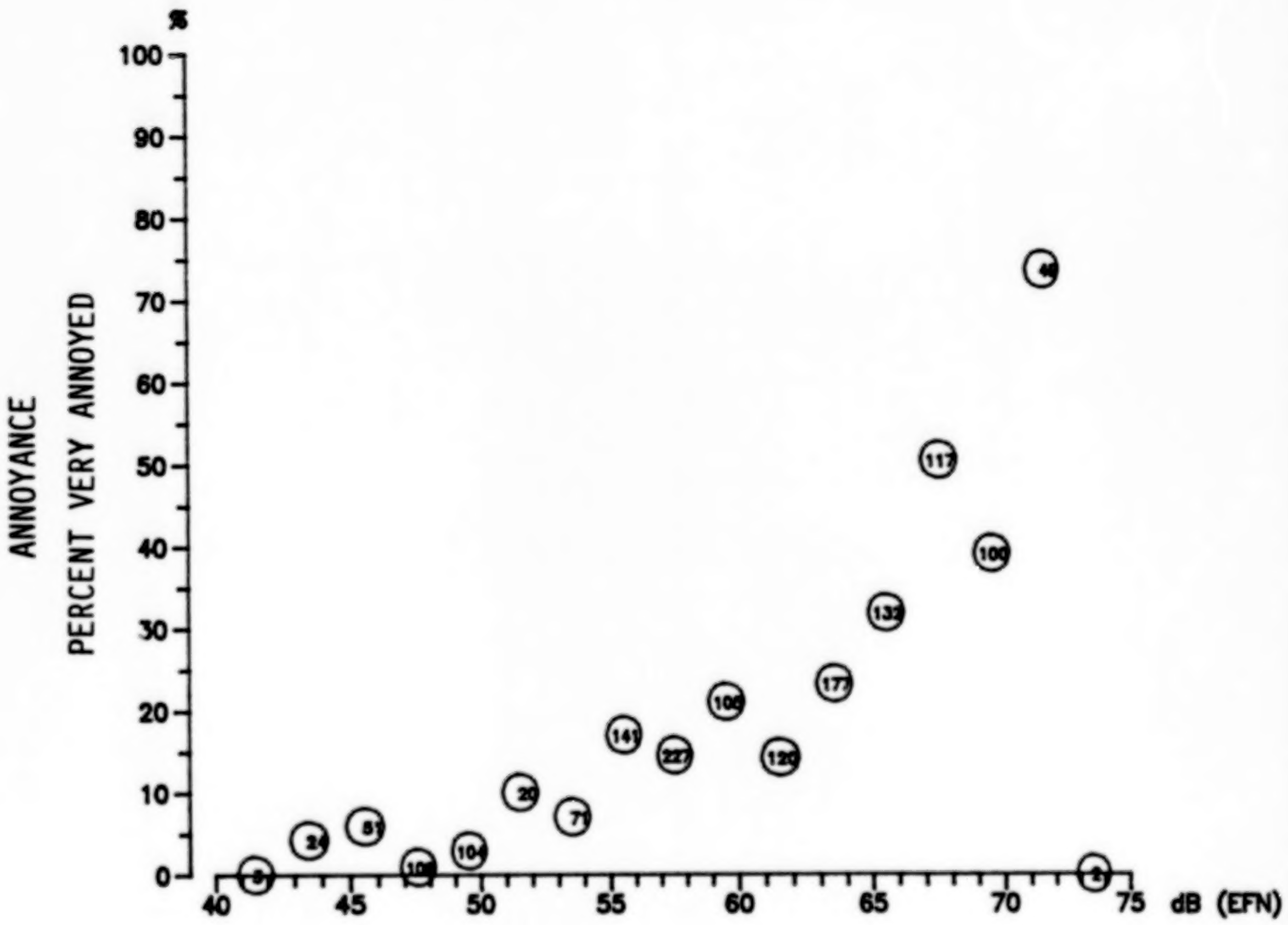

Figure 1. Results from the Fornebu survey
Percentage of people very annoyed as a function of noise exposure. Circled numbers indicate number of respondents for each noise level.

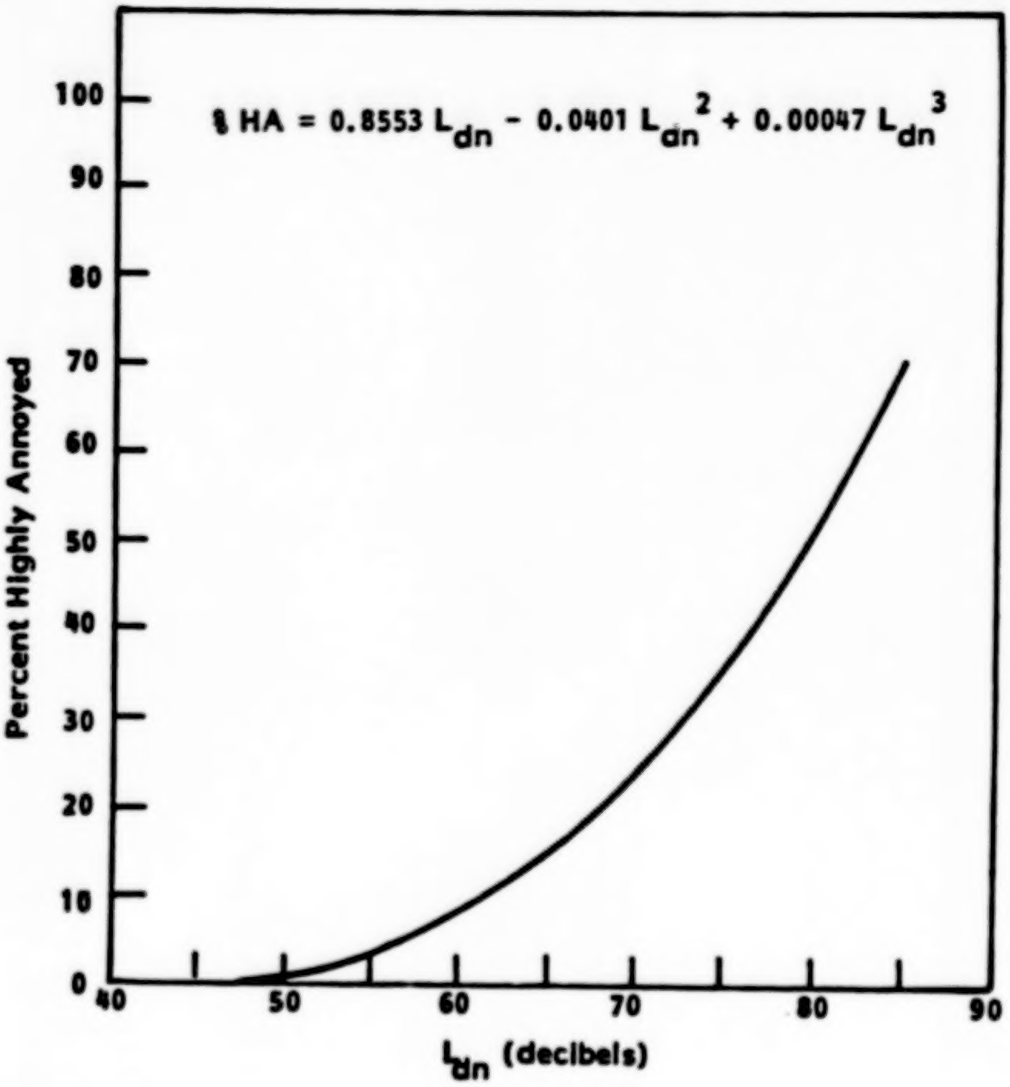

Figure 2. Dose-effect relationship for annoyance associated with general transportation noise according to Schultz; 1978

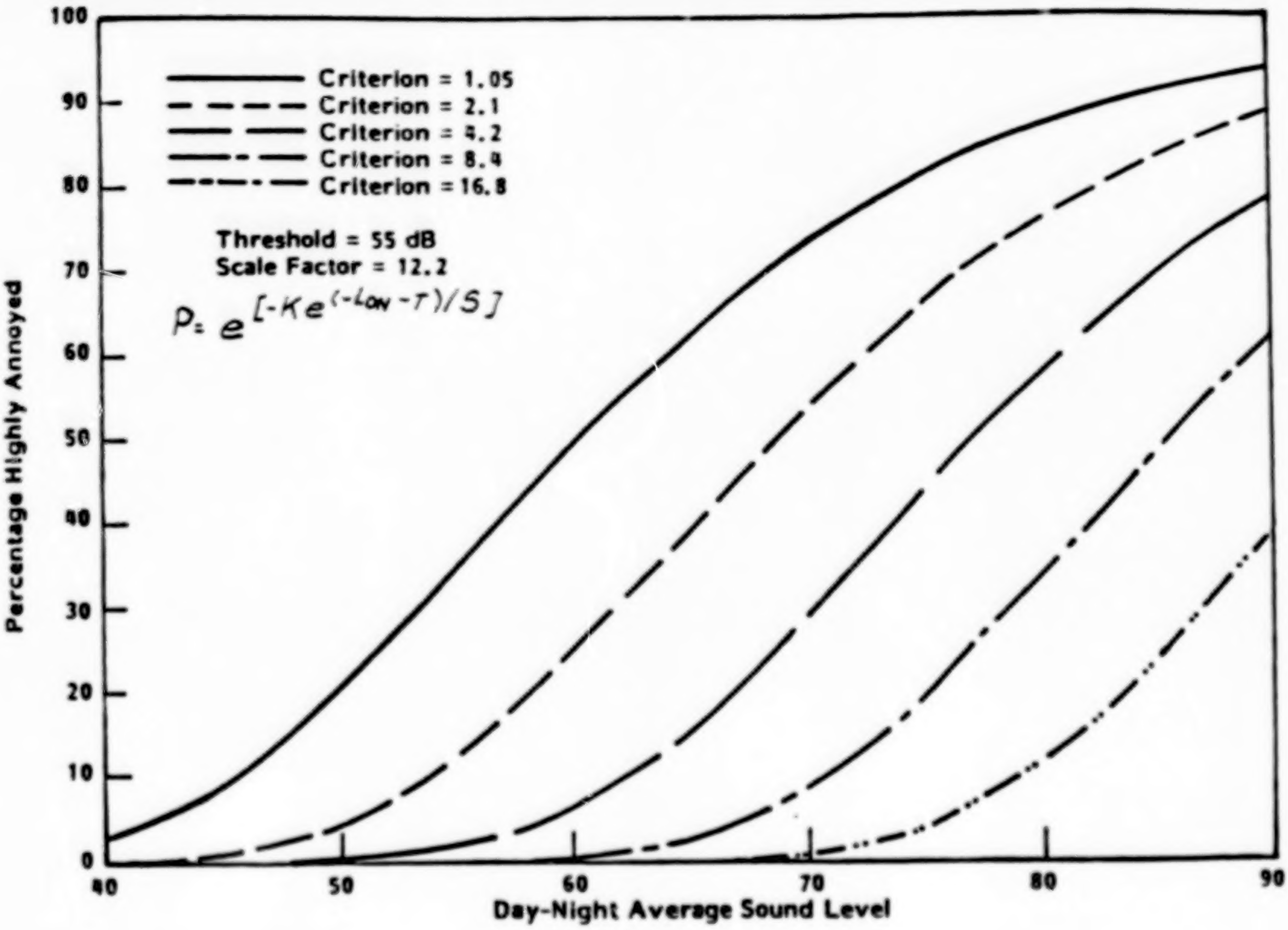

Figure 3. Effect of changing criterion for reporting high annoyance on dose-effect relationship; Fidell et al. 1987

There are two basically different processes that govern an individual's response to noise. At low levels up to a certain threshold, the noise is "tolerated" and represents only a certain "disturbance". If the response to a stimulus in this region follows traditional psycophysical theory, Weber's and Fechner's laws may be applied. Hence a function showing the relationship between degree of disturbance/annoyance and noise level in dB should be a straight line.

In any given situation there is a certain level, however, at which the noise changes from "just disturbing" to "really annoying". This situation may be explained by a threshold concept. We discussed the hypothesis with T.J.Schultz and he suggested the following possible explanation:

" I think we adopt 'contracts' among ourselves in order to live close together in communities. These 'contracts' are not usually acknowledged or even recognized, and certainly the number of 'clauses' is never known (much less their content). But they are there. They are not enforceable, obviously, until enough people realize that their 'agreement' is being infringed upon. And then it becomes a stickier matter with lawyers and courts who have never quite realized the nature of the 'implicit contracts' that determine the boundaries between undeniable 'disturbance' and 'annoyance', which appear when the contract has been felt to be breached."

In terms of reaction to noise the 'contract' implies that an individual has a certain limit of tolerance, and as long as the noise levels stay below this limit, the reaction follows a certain pattern as explained above. When the 'contract' is broken, however; that is, the noise increases above the limit silently agreed upon, the individual reacts immediately, and the reaction is of a different kind than in the 'disturbance mode'. The reaction to noise above this threshold follows a different psycophysical 'model', but again Weber's and Fechner's laws should be applicable. Hence a reaction versus noise plot in this level region will also be a straight line.

According to this hypothesis the relationship between degree of disturbance/annoyance and noise exposure can be depicted by two straight lines with a discontinuity at a certain threshold level.

The threshold level is an individual quantity and may vary depending on expectations, activity, location, time of day, etc. Different people within a community will have different thresholds. On a community basis we will therefore see a transition interval rather than a fixed noise threshold, but for simplicity reasons we may still use a single threshold level for our discussion.

Reported differences in community reaction to noise may thus be explained by differences in the threshold level for onset of the annoyance reaction. In a busy community with a high ambient noise level, we may expect a high tolerance threshold, where as the people living in a quiet rural area have a low threshold. This fact makes it impossible to compare dose-response relationships found in one community with those from another community without considering the possibility that the 'community reaction thresholds' are different.

The threshold is most likely associated with the instantaneous noise level rather than the equivalent level or a similar 'average' noise index. Differences in the reported annoyance in areas with equal LEQ may therefore also be explained by differences in the noise exposure pattern, even though the reaction thresholds are the same.

At a conference in 1988 we presented a paper indicating that location relative to the flight path was an important parameter for predicting the annoyance from aircraft noise (5). People living underneath the take-off flight path seemed to report a higher degree of annoyance than people living outside those areas.

For equal LEQ each noise event observed underneath the flight path has a shorter duration and higher maximum level than at other locations. This means that people living underneath the flight paths are more likely to feel that 'their contract has been breached', and they react more often according to the 'above threshold psychophysical model'.

Discussion

In figure 4 we have fitted linear regression lines to the results from the Fornebu study. The dashed line (r=.865) is fitted to the complete data set. We get a better fit, however, if we assume a change in the reaction pattern around 60-65 dBA. The two solid lines are based on data points 42-65 dBA (r=.911) and 60-74 dBA (r=.878). These results indicate a possible discontinuity in the 60-65 dBA region.

According to our previous findings we divided the different respondents into three groups depending on their residence. By using the information from the flight track recorder we could define three types of locations: areas underneath the approach flight paths, areas underneath the take-off flight paths, and areas never (or seldom) overflown.

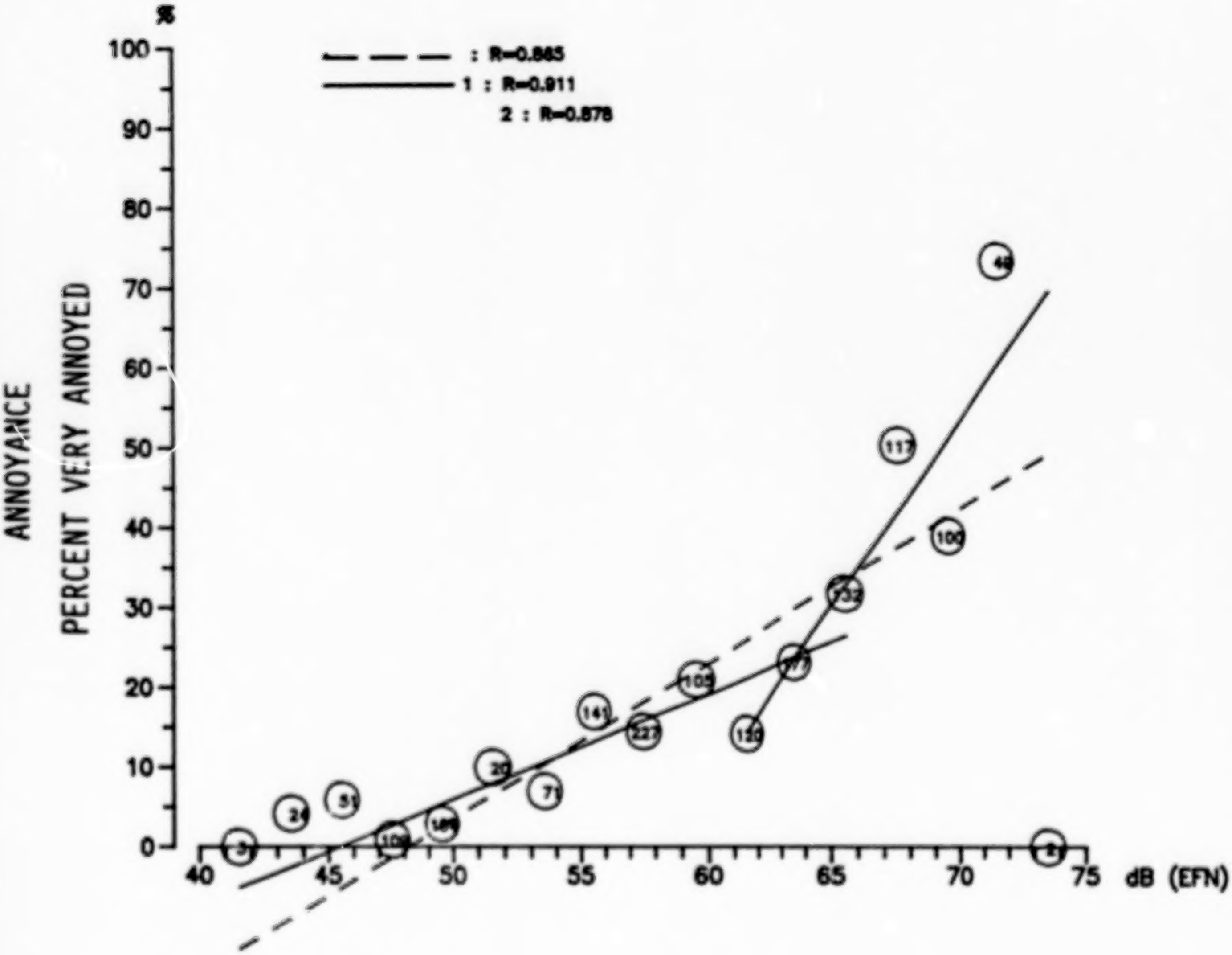

Figure 4. Results from the Fornebu survey
Percentage of people very annoyed as a function of noise exposure.
Dashed line: linear regression to all data points
Solid line: two regression lines, 42-65 dBA and 60-74 dBA

Figure 5 shows the response from people living in the approach path areas. A single regression line has a correlation coefficient r=.701 where as a two-stage method yields r=.775 for the 42-65 dBA region (477 respondents) and r=.484 for the 60-74 dBA region (149 respondents).

Figure 6 shows similar results from the take-off areas. The total number of respondents is only 242 with most of them experiencing noise exposure above 60 dBA. A regression line is therefore fitted to the whole data set. The correlation coefficient is r=.789.

Figure 7 shows the results from areas outside the flight paths. A single regression line gives r=.908, whereas two lines for the same exposure regions as above have correlation coefficients r=.953 (730 respondents) and r=.747 (365 respondents).

Conclusions

The total material is not large enough to draw firm conclusions. In the next phase of the study, however, we will have the results from an additional 1800 respondents. Hopefully these results will confirm our hypothesis.

We think the higher annoyance score observed in the take-off areas can be explained by the fact that people in these areas are exposed to higher instantaneous noise levels, and hence the probability of reacting according to the 'annoyance model' rather than the 'disturbance model' becomes greater.

One way of discriminating noise exposure that actually contributes to annoyance from noise exposure that is not of great enough magnitude to be recognized as such is to introduce a threshold level. We have shown in (3) that the equivalent level measured only for those periods that the noise level exceeds a certain threshold is a good descriptor for noise annoyance. Laboratory experiments have confirmed that the equivalent level with threshold, LTEQ, is superior to the regular LEQ in predicting subjectively reported noise annoyance (4).

Moreover, this index, LTEQ, is based on a psychophysical model. In his book, Community Noise Rating, (6) Schultz reviews different noise indices. In a comparison between LEQ and LTEQ he points out: "Not only is the correlation coefficient higher and the standard error of estimate lower for the plot against LTEQ (annoyance versus noise exposure), but the latter curve presents a much more plausible-looking fit to the data points than the LEQ curve."

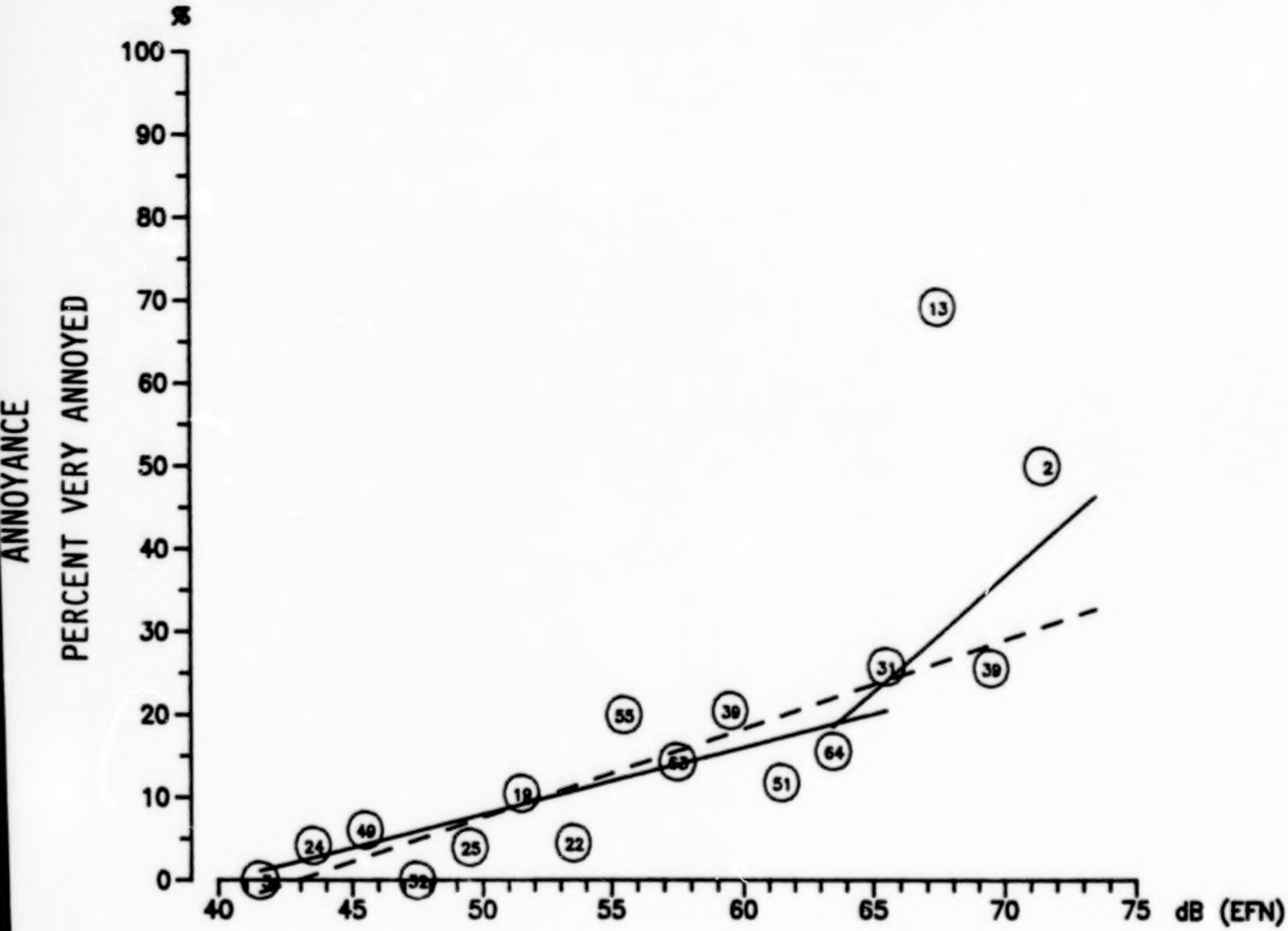

Figure 5. Results from the Fornebu survey
Percentage of people very annoyed as a function of noise exposure for respondents living under the approach flight paths.
Dashed line: linear regression to all data points
Solid line: two regression lines, 42-65 dBA and 60-74 dBA

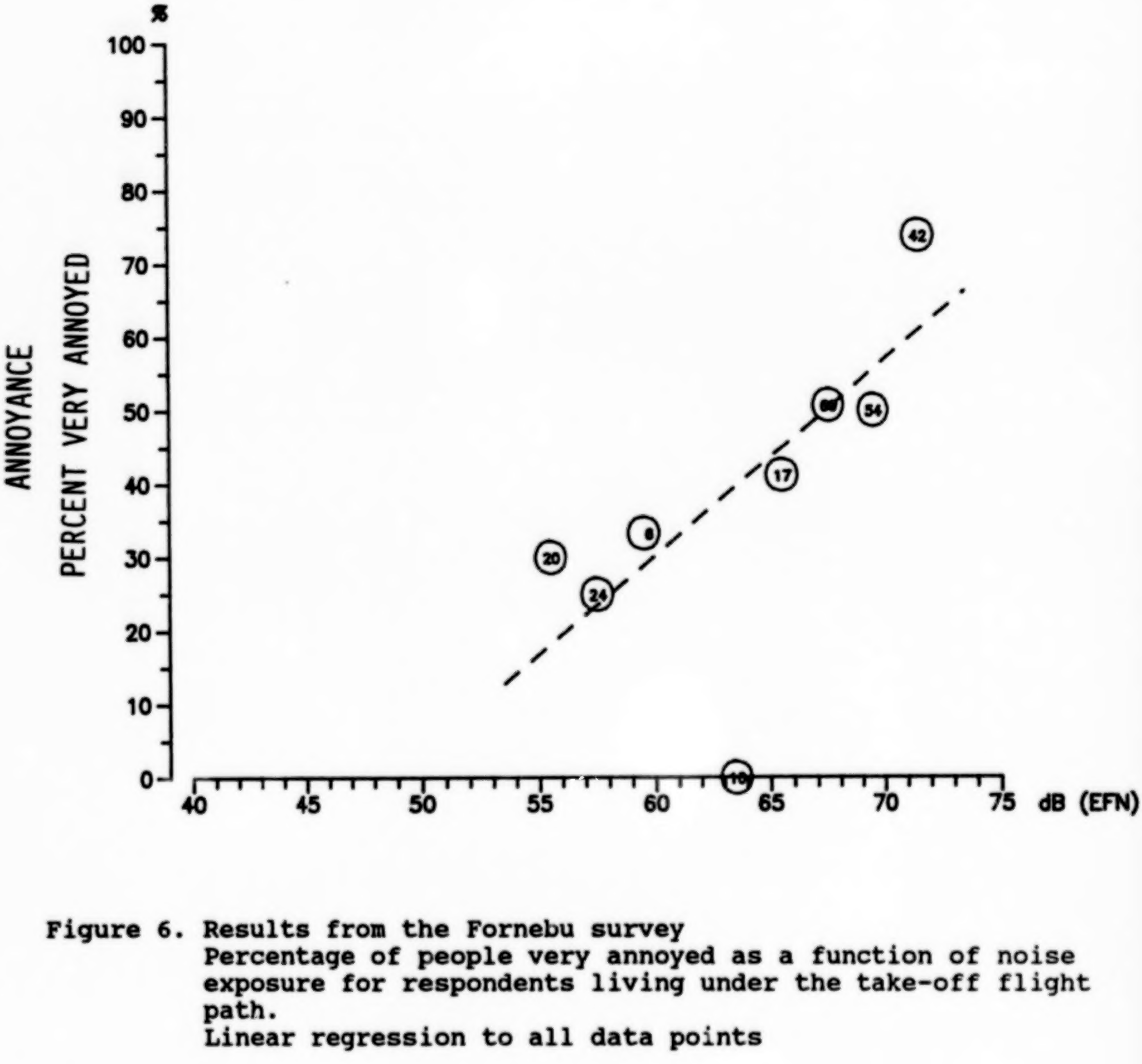

Figure 6. Results from the Fornebu survey
Percentage of people very annoyed as a function of noise exposure for respondents living under the take-off flight path.
Linear regression to all data points

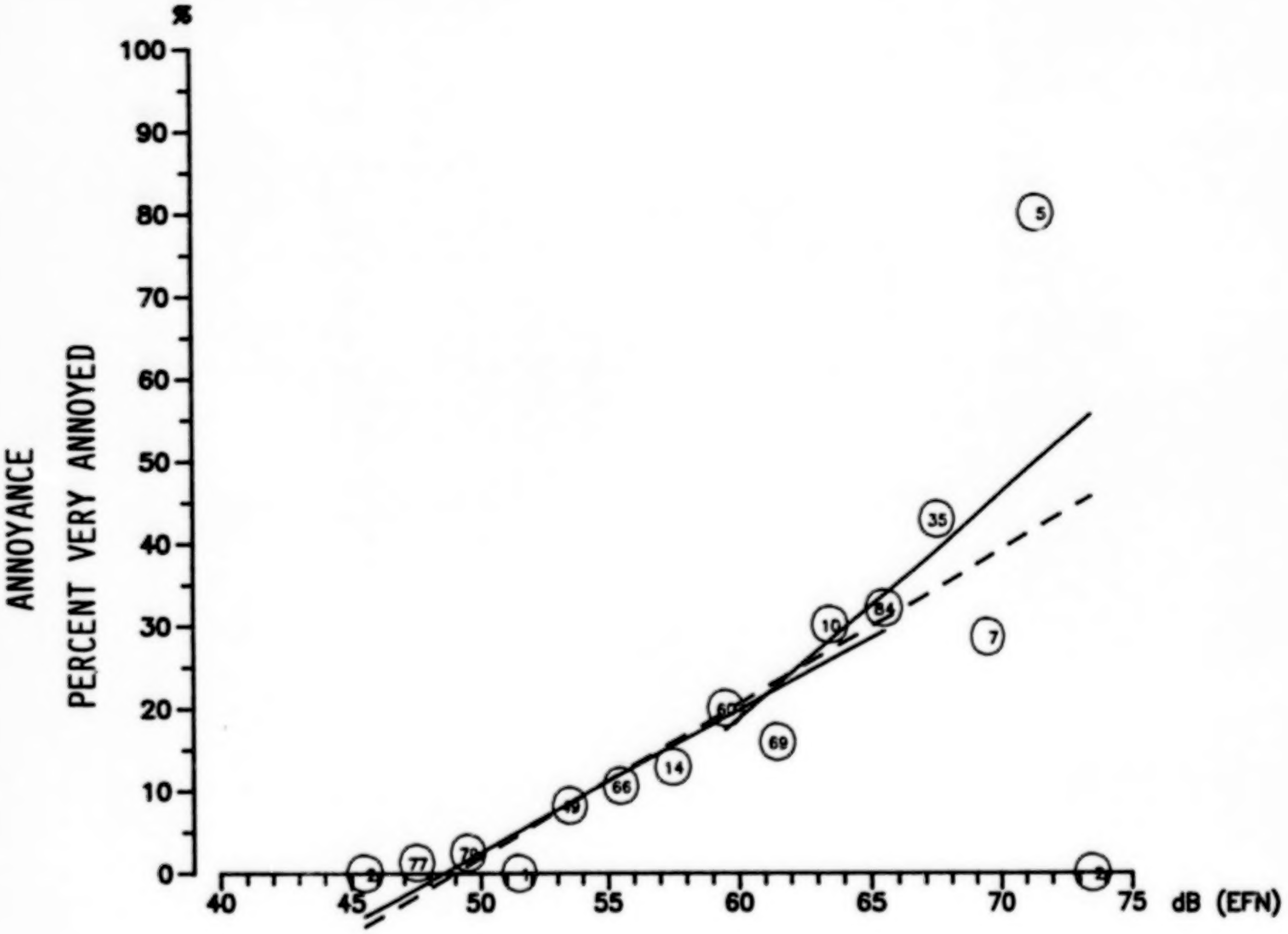

Figure 7. Results from the Fornebu survey
Percentage of people very annoyed as a function of noise exposure for respondents living outside the flight paths. Dashed line: linear regression to all data points Solid line: two regression lines, 42-65 dBA and 60-74 dBA

With the combined data from the two surveys around Fornebu Airport, we hope to confirm the hypothesis that the annoyance is a function of exposure to noise above a certain threshold, and that this threshold depends on community expectations rather than a fixed quantity. If this conclusion is valid, results from noise surveys around busy airports cannot be used to predict aircraft noise in other areas, for instance en route noise experienced in rural areas. The reaction to noise in these areas may be expected to be much higher, as the probability that the annoyance threshold is exceeded, is higher.

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To a good friend, Ted Schultz.

HUMAN RESPONSE RESEARCH UPDATE

Paul D. Schomer
U.S. Army Construction Engineering Research Laboratory

U.S. ARMY CERL

HUMAN RESPONSE RESEARCH UPDATE

METHODOLOGY
SOURCES
FACILITIES
RESULTS

METHODS

- PAIRED COMPARISON
- BAND-LIMITED WHITE NOISE
- HAYSTACK PATTERN
- VARIABLE LENGTH

SOURCES

- HELICOPTER - 500Hz OCTAVE BAND
  1 MINUTE DURATION
  VARIABLE 10 dB DOWN

- BLAST - 200 - 1500Hz WHITE NOISE
  ½ SECOND DURATION
  FIXED SHAPE

INSTRUMENTATION

- COMPUTER CONTROLS
  - TIMING (LIGHTS)
  - CONTROL SOURCE
  - MICROPHONE GAINS
  - DATA ANALYSES

- MACHINE READ QUESTIONNAIRES

TESTS

- HELICOPTER
  - CHAMPAIGN - UH1H - 200 SUBJECTS
  - CALIFORNIA - UH1H, UH1N, CH-46, CH-53 A/D
    CH53 E, AH-1G
    - 600 SUBJECTS
- BLAST
  - CHAMPAIGN - 5 HOUSE CONFIGURATION
    300 SUBJECTS
  - GRAFFENWOHR W. GERMANY
    2 HOUSE CONFIGURATIONS
    150 SUBJECTS
  - ABERDEEN PROVING GROUNDS
    NEW

RESULTS

- RATTLE
- LOUDNESS
- DETECTION (BACKGROUND)

NEW FACILITY
ABERDEEN PROVING GROUNDS

- WOOD HOUSE
- MASONRY HOUSE (GERMAN) EACH WITH 2 "APARTMENTS", GERMAN & AMERICAN
- OUTDOORS

5 LOCATIONS TOTAL (25 SUBJECTS)
★ NO NEAR NEIGHBORS

OUR TESTS

- BLAST NOISE
  - WINDOWS
  - WALLS

APG - SOURCES

- IN LINE WITH CROSS-RUNWAY
  - HELICOPTERS - FLYOVER, TAKE OFF, LAND
  - BLAST
  - FIXED-WING - FLYOVER, TAKE OFF, LAND
  - VEHICLES (PARTIAL)
  - ANY RECORDED SOURCES

- FUTURE USES OF APG
  - COMPARATIVE SOURCES
- NEVADA SITE

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16. Abstract

Aircraft community noise annoyance is traditionally a concern only in localities near airports. The proposed introduction of large commercial airplanes with advanced turboprop propulsion systems with supersonic propellers has given rise to concerns of noise annoyance in areas previously considered not to be impacted by aircraft noise.

A symposium, jointly sponsored by the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA), was held at the NASA Langley Research Center, September 12-13, 1989, to assess the current knowledge of factors important to the impact of en route noise and to aid in the formulation of FAA and NASA programs in the area. Papers were invited on human response to aircraft noise in areas with low ambient noise levels, aircraft noise heard indoors and outdoors, aircraft noise in recreational areas, detection of propeller and jet aircraft noise, and methodological issues relevant to the design of future studies. This report is a compilation of the presentations made at the symposium which addressed the above issues and consists of measurements of en route noise, data on human response to en route or related noise, experiences related to the major questions of en route noise, and planned research to address those questions.

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